MAY 1957

THE WELDING JOURNAL

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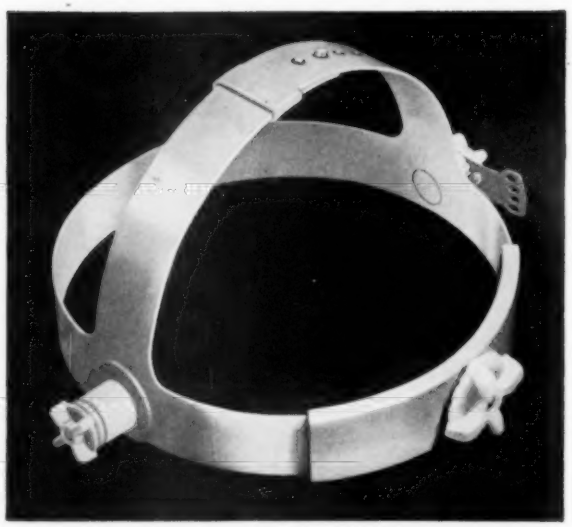

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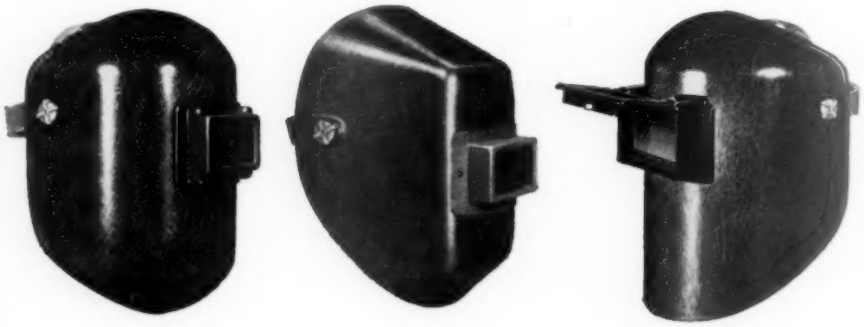

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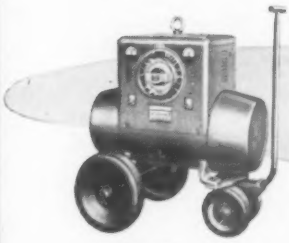

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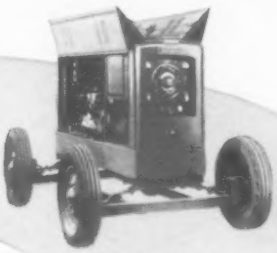

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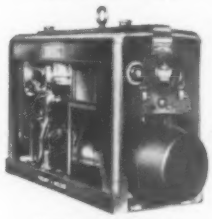

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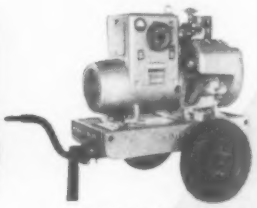

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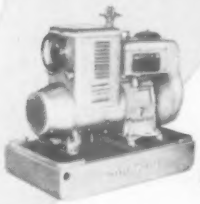

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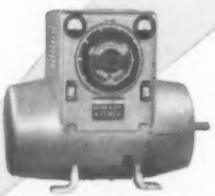

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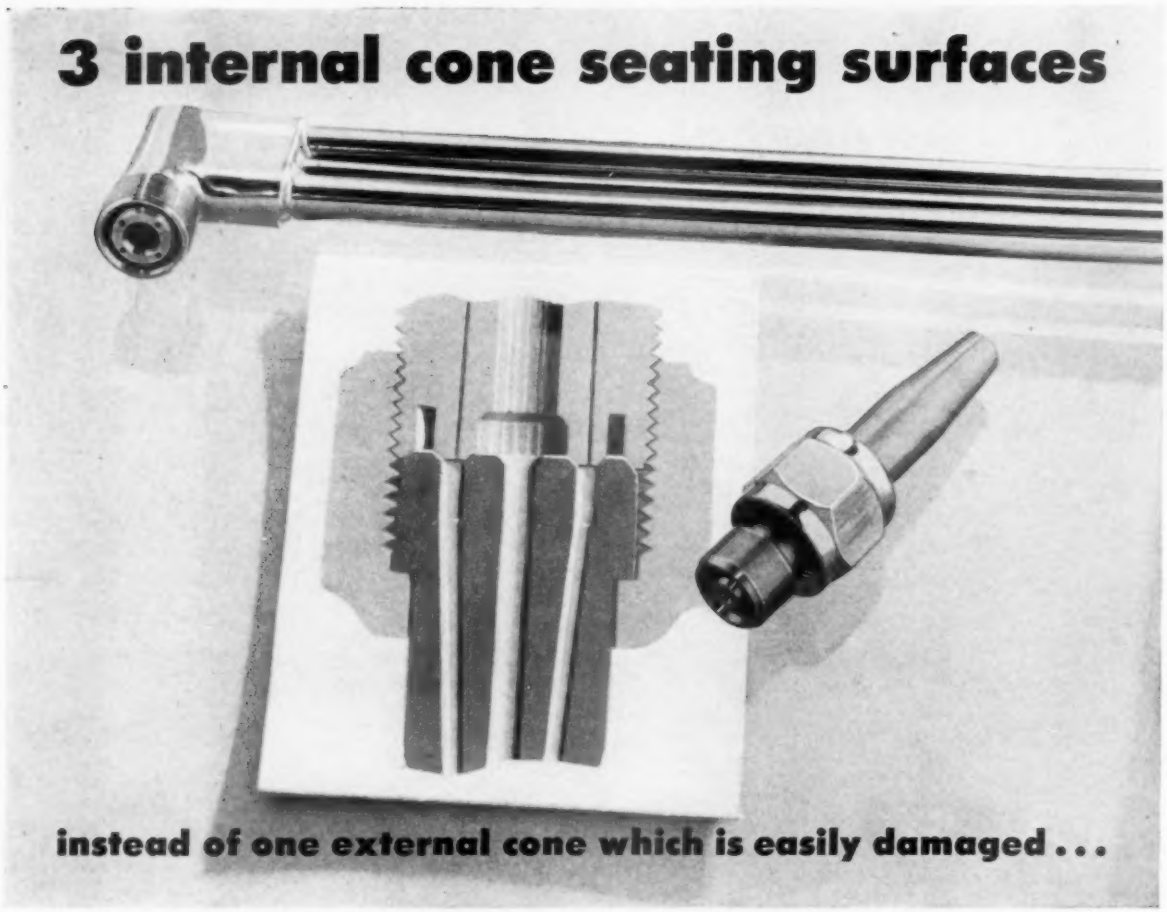
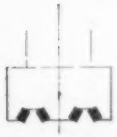
3 internal cone seating surfaces



instead of one external cone which is easily damaged . . .

internal conical seat surfaces do it . . .

external cone — easily damaged



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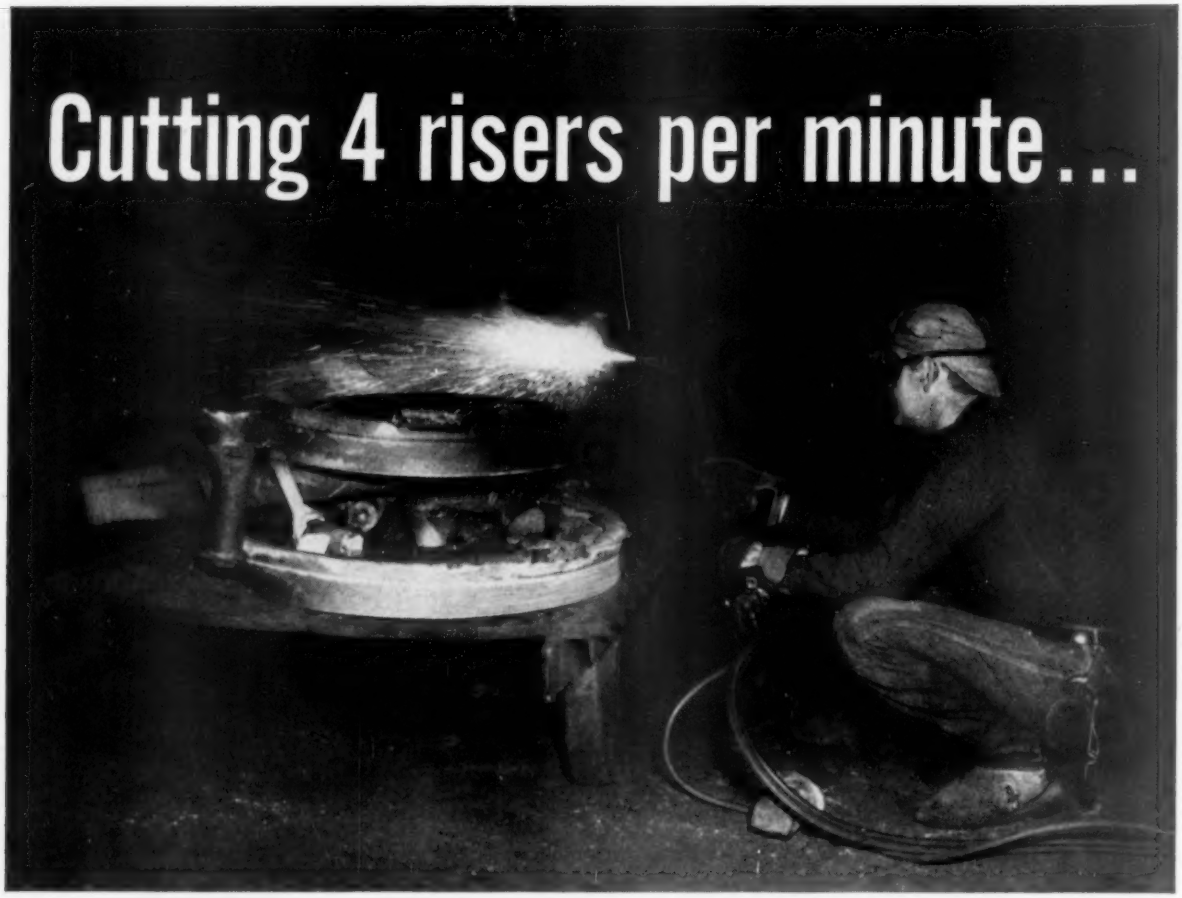

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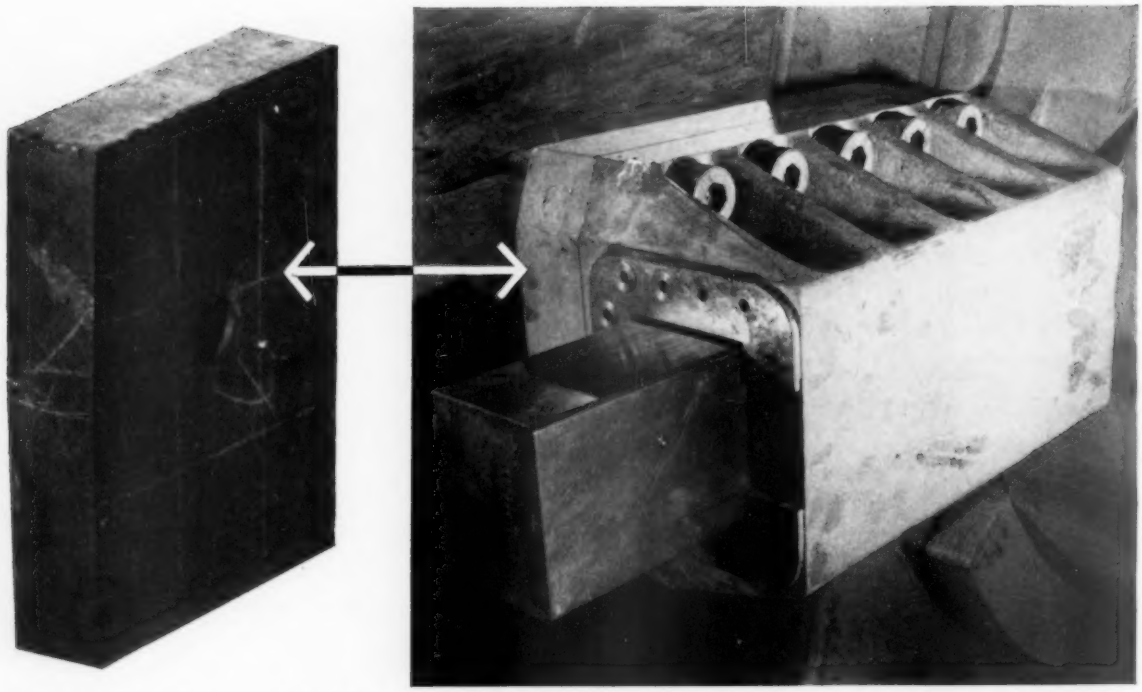

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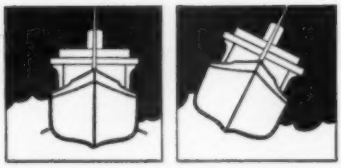

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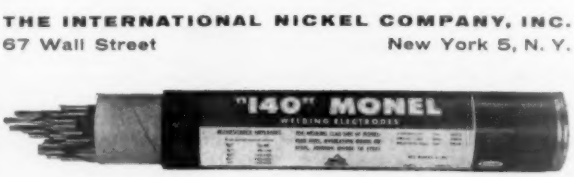

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WELDING IN THE POWER INDUSTRY

The march of progress in the power industry has been made possible by technological achievements in many facets of engineering. Among these, the contributions of the welding industry have been outstanding.

A major factor in the development of equipment capable of producing electric power at greater and greater efficiencies has been (1) the improvement in welding techniques and (2) better knowledge of metallurgy, particularly as applied to higher operating temperatures and pressures.

Welding became an important fabricating tool in the power industry about a quarter century ago, when it began to replace riveted construction of boiler drums and other equipment. An all-welded boiler drum fabricated from 1-in. thick plates was built to test the use of welded joints. Failure of this drum occurred at more than six times the normal working pressure, but the failure did not occur at the weld. This and similar tests proved the case for welding and today we have all-welded boiler drums constructed from plate over six inches thick. Only through assiduous research and pioneering in the welding industry was this milestone of progress made possible.

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Positioning a gamma-ray projector prior to making the radiograph. Distance from projector to nearest surface of subject determines size of plane of focus. To radiograph a greater area, projector would be positioned at greater distance from subject

INDUSTRIAL RADIOGRAPHY BY GAMMA-RAY PROJECTION FROM RADIOACTIVE ISOTOPES

Comparatively low initial cost of equipment, ease and convenience of using it, and effective results are claimed as advantages of the gamma-ray radiography process

BY CHARLES M. DICK

Charles M. Dick is a Special Representative, Metal & Thermit Corp., Rahway, N. J.

Presented at the 1956 AWS National Fall Meeting, Cleveland, Ohio, October 8–12.

Introduction

Radiography is defined by the American Society for Metals Committee on Radiography as "a method of nondestructive inspection that produces a shadow image of the exterior and interior of an object by means of absorption in the object of penetrating radiation from a radiation source, and the registration of the varying intensities on an image-detecting medium."

In simpler terms, radiography is accomplished by passing X-rays or gamma rays through the object to be examined onto a film placed on the opposite side of the object from the source of the rays. The radiation must penetrate the object before reaching the film. The

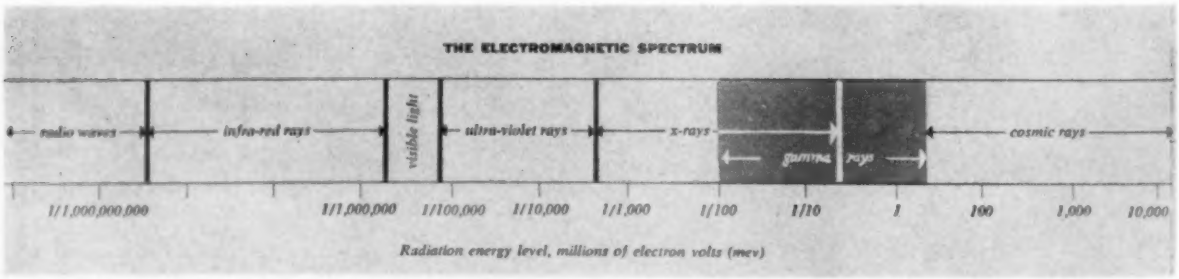


Fig. 1 The Electromagnetic Spectrum, showing relative radiation energy levels, in millions of electron volts (mev)

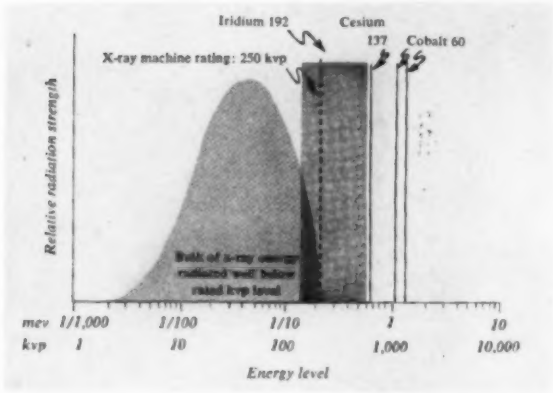


Fig. 2 Energy level diagram, showing energy levels of three radioisotopes commonly used for radiography, compared with that of a 250 kvp X-ray machine

image, which is a geometrical projection of the object, reproduces external and internal details of the object by variations in the amounts of radiation passing through to the film.

Theory of Flaw Detection

Flaws or discontinuities in the internal structure of the object could pass more or less radiation to the film than the solid portions of the object, thus showing a density difference between the discontinuity and the surrounding area of the object being radiographed. When the film is developed, the imperfections can therefore be detected as darker or lighter spots in the image. Thus a void such as a gas pocket or slag inclusion in a weld will appear on the film as a darker spot than the adjacent area because the rays will have passed through the void more readily than through the surrounding area.

Prior to 1939, radiography was not used very extensively in industry as an inspection method. During World War II, however, industry was called upon to supply equipment to meet more rigid specifications than previous requirements. Radiography rapidly assumed increasing importance as a means of determining the internal soundness of materials. During the war period the high cost of natural radioactive materials such as radium was not as great a deterrent as it formerly had been, and much use was made of gamma radiation for testing and improving welding techniques.

Because of the wartime success of welding shops in improving the skill of their workmen, many of the companies that employed gamma radiography wished to continue its use after the war. However, the high cost of radium and of the radioactive isotopes produced by the methods then available was a deterrent to widespread use of the process.

Later, when the nuclear reactor could be used for peacetime purposes, however, it became possible to produce comparatively large quantities of radioisotopes at low cost. The availability of inexpensive radioisotopes of sufficient intensity to permit shortened exposure times has provided a strong stimulus, and the use of gamma rays in the radiography of castings, forgings and welds is now well established.

Characteristics of Radioisotopes

In the radiographic system to be described here, three different radioisotopes are commonly employed as sources of energy. These are Cobalt^{60}, Cesium^{137} and Iridium^{192}.

Before we can differentiate between these energy sources, or evaluate their relative potential for radiographic work, it is necessary to devote a few minutes to the characteristics of radiant energy in general. The electromagnetic spectrum (Fig. 1) is the chart on which scientists arrange all known types of radiant energy. Like the visible spectrum which forms a part of it, the electromagnetic spectrum is simply a classification of radiation on the basis of its frequency. Different units are used in different parts of this spectrum to measure frequency (or wave length, which is the radiation velocity divided by the frequency), but these units are directly convertible into one another. Radio waves are usually expressed in cycles per second (the familiar kilocycles and megacycles); light rays in Angstrom units; and X-rays, gamma rays and cosmic rays in millions of electron-volts or *mev*—a unit which defines the energy level of the radiation source. In the spectrum in Fig. 1 the various types of radiation are arranged by *mev*.

A more accurate evaluation of penetrating power is to identify the radiation by its position on the kvp (kilo volt peak) or mev scale. In Fig. 2 it will be seen that Iridium^{192} produces a band of radiation around the 400 kvp point, Cesium^{137} a sharp line at 661 kvp,

Table 1—Important Characteristics of Radioactive Sources Commonly Used for Industrial Radiography

Radioactive element	*Half life, yr*	*Energy of gamma rays, mev**	*Gamma ray dosage rate per curie, rhm†*	*Max available specific activity, curies per cu cm*
Radium	1620	0.24–2.20‡	0.84	Variable
Cesium—137	37	0.66	0.39	40
Cobalt—60	5.3	1.17 and 1.33	1.35	180
Iridium—192	70 days	0.137 to 0.651§	0.55	1100

* Million electron volts. † Roentgens per hour at 1 meter, neglecting self-absorption. ‡ Eleven principal gammas. § Twelve gammas.

and Cobalt[60] two distinct lines at 1170 and 1330 kvp. Figure 2 also demonstrates an important practical difference between radiation produced by X-ray machines and that given off by radioisotopes, which is that X-rays cover a very broad band while gamma rays are confined to narrow ones. The result is that X-rays have considerably less penetrating power than would be indicated by the kvp rating. A glance at the diagram shows why: an X-ray machine rated at 250 kvp discharges the bulk of its radiation well below this level.

Comparison of Energy Levels

Another way to compare the energy levels is shown in Table 1. Here the three isotopes produced in the atomic pile are compared with radium as to half-life, energy of the rays and gamma dosage rate per curie in roentgens per hour at a distance of 1 meter.

The term half-life requires some explanation. Since radioactive isotopes generate gamma rays by a continuous process of atomic disintegration, the strength of the radiation slowly diminishes with the passage of time. The half life of a radioisotope is the time required for half of its atoms to decay. The fact that a radioisotope has a short half life is not wholly disadvantageous. A short half life indicates an isotope of high specific activity, with corresponding high radiation intensity and short radiographic exposure time.

The term "specific activity" denotes the number of atomic nuclei disintegrating per second in a given amount of material. Specific activity is usually expressed in curies per gram or curies per cubic centimeter. One curie has been established as one gram of radium.

A 50-curie source of Cobalt[60] for the radiographic system under discussion is approximately 10 mm in diameter by 10 mm long and weighs about 5 g. The source strength is more accurately termed the source activity. This means that a 50-curie source of energy is 50 curies activity. Since the activity of the Cobalt source is 50 curies and the weight is 5 g, the "specific activity" of this source is 10 curies per gram.

A 5-curie Iridium[192] source, used in small portable equipment, is 1.6 mm in diameter, and the specific activity of this source is up to 60 curies per gram. The 50 to 70 curie source of Iridium[192] is 2.8 mm in diameter.

The specific activity of Cesium[137] is approximately 25 curies per gram.

Penetrating Power of Sources

The penetrating power of the three radioisotopes and of radium is shown in Table 2. The horizontal measurement is shown in approximate inches of thickness of steel. Practical limits of penetration for the three isotopes are as follows:

Iridium[192]: 1/8 to 3 in.
Cesium[137]: 1/4 to 4 in.
Cobalt[60]: 3/4 to 8 in.

It should be noted that the minimum thickness is important as well as the maximum penetration. For example, while Cobalt[60] can readily penetrate 8 in. of steel, it should not be used for thickness less than 3/4 in. On thinner sections, better definition and clarity of image will result from the use of either of the other two sources.

Table 2—Approximate Practical Thickness Ranges of Radioactive Sources for Steel

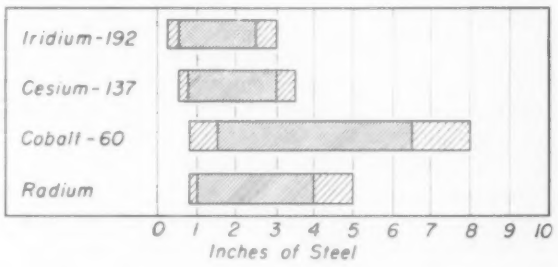


Fig. 3 A modern gamma-ray projection device

Original experiments with gamma-ray radiography were carried out with unshielded "free" sources. Theoretically, all that is required to produce radiographs by gamma rays is a pellet of radioactive material on one side of the object and a sheet of photographic film on the other. In industrial practice, however, such an arrangement could be impractical and hazardous. For convenience, speed of operation and safety, the isotope must be mounted in a properly-designed projection device (Fig 3).

Functions and Sizes of Projectors

The primary function of the projector is to provide a shield from the radiation. Radiation from the isotope must be effectively blocked when the projector is not in use. The projectors used in our system of radiography are shielded with lead and other denser materials. Since the isotopes have different energy levels, it is necessary to have varying thicknesses of shielding to safely contain these sources. In modern gamma-ray projectors, shielding is so complete that when the shutter or the projector is closed men can work next to the machine in complete safety.

The projector also provides directional control of the radiation. An unshielded radioactive source emits radiation in all directions. Mounting the source in a projector provides the means for adjusting the surrounding shielding to produce the pattern of radiation desired.

A third and vital reason for the instrument is safety. Unshielded radioisotopes cannot be handled except by highly trained personnel using remote-handling equipment. The projector serves the purpose of shielding the source under all conditions: in transit, in storage and in use.

Three sizes of projectors are available in our system of radiography. The largest size has a cast stainless-steel case approximately $^3/_8$-in. thick. This shell is filled with lead with a mallory metal or tungsten insert adjacent to the isotope to increase the effective shielding. When set in the "Off" position, this projector has a minimum of 8.5 in. of lead between the source and the case. This projector is designed to contain a 50-curie source of Cobalt^{60} or 85 curies of Cesium^{137}. The Cobalt limitation is set by the shielding while the Cesium limitation is determined by the physical dimensions of the source itself.

The medium size projector has a $^1/_4$-in. stainless-steel shell and is filled with lead and other shielding material to provide a minimum thickness of 3.5 in. of shielding around the source in the "Off" position. This size accommodates 20 curies of Cesium^{137} or up to 70 curies of Iridium^{192}, both limitations being imposed by the type of shielding.

Types of Radiation Patterns

Since the two larger models are of similar design, we can discuss their radiation patterns together.

The spot projection (Fig. 4) is made by first removing the screw plug in the head of the projector. This reveals a cone-shaped aperture with a 60-deg included angle which becomes the pattern for the gamma rays when the projector is turned "On." The diameter of the area receiving radiation is approximately the same in inches as the souce-to-film distance.

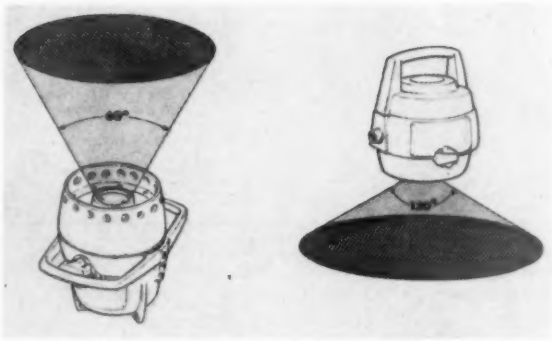


Fig. 4 Diagram of conical patterns of radiation

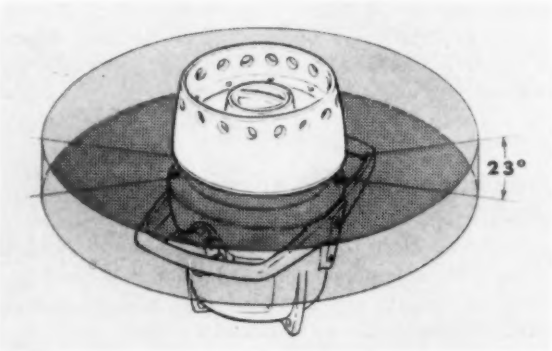


Fig. 5 Panoramic or circumferential radiation pattern

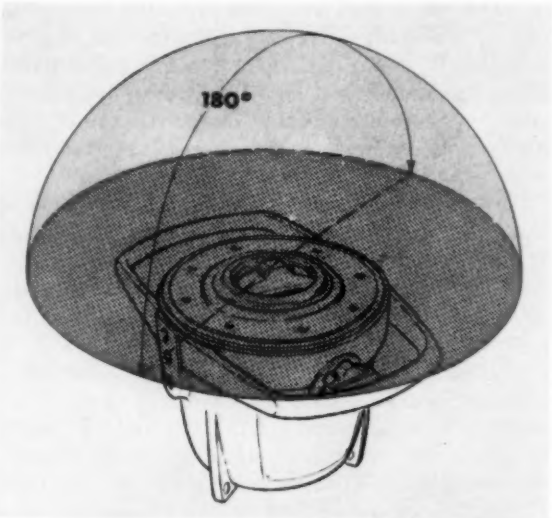


Fig. 6 Hemispheric or dome-shaped radiation pattern

The second pattern of radiation is the circumferential or panoramic pattern (Fig. 5). This is accomplished by inserting an aluminum ring between the head and the body of the projector. When the projector is

turned to the "On" position, the isotope is located directly in back of the aluminum ring. The thin aluminum ring, being of low density, offers little resistance to the rays; thus, they are emitted in full circumferential pattern.

The third pattern of radiation (Fig. 6) is achieved by completely removing the head from the projector. When turned to the "On" position, the source then extends beyond the body of the projector. This permits a full hemispheric or dome-shaped emission of the gamma rays.

The smallest projector is designed for spot projection only with a radiation pattern of 120 deg. This model also has a stainless-steel shell and a minimum of $2^1/_2$ in. of shielding around the source in the "Off" position.

Internally all three sizes are of the same basic design. The encapsulated isotopes are fastened into a small cavity in the circumference of a rotor of approximately the same diameter as the minimum thickness of the shielding (Fig. 7). This rotor is centered on a shaft which is mounted 90 deg to the longitudinal axis of the projector. By rotating this shaft 180 deg, the source is moved from the "Off" position in the center of the case to the "On" position at the forward end of the body (Fig. 8). The bearings at the ends of the shaft and the receptacle into which the capsule has been screwed are the only moving parts within the projector. This design affords a strong piece of equipment which should require no maintenance beyond the normal care given any production tool.

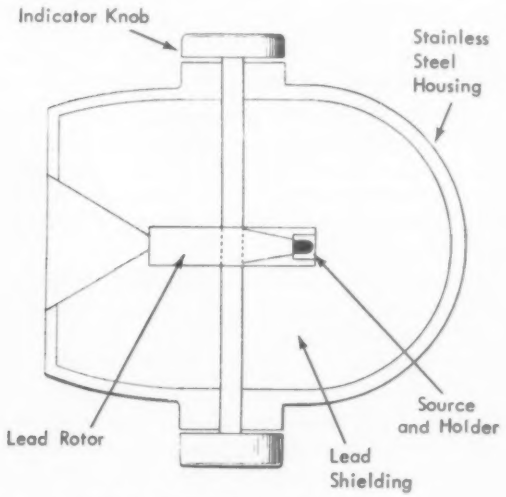


Fig. 7 Source in the "Off" position

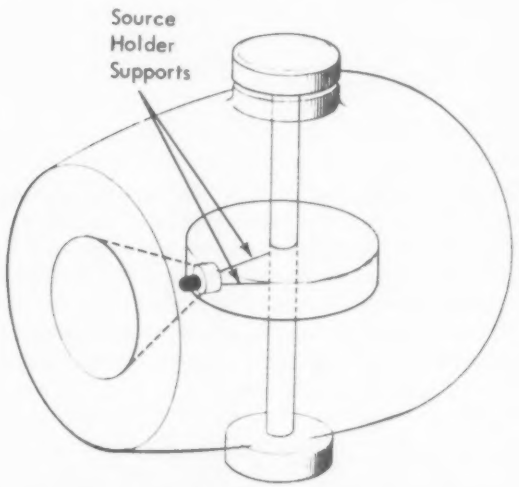


Fig. 8 Source in the "on" position

Portability and Safety Features

Gamma-ray projection equipment offers many economies in operation compared with X-ray equipment. Because it is not a delicate piece of equipment, it does not require special packaging and handling. It needs no external power supply or separate pieces of power generating equipment. It is readily placed in position by means of cranes, rope blocks, lift truck or other means in a short time (Fig. 9). An especially noteworthy economy feature is the opportunity to use the circumferential or panoramic exposure patterns in which many films can be exposed in a single setup.

Extreme precautions have been taken in the design of these gamma-ray projectors to assure complete safety for the operator and other personnel. Shielding is so thorough that it is impossible for a person working right beside the projector, for 40 hr in one week, to receive over 300 milliroentgens which is the maximum allowable weekly dosage established by the Atomic

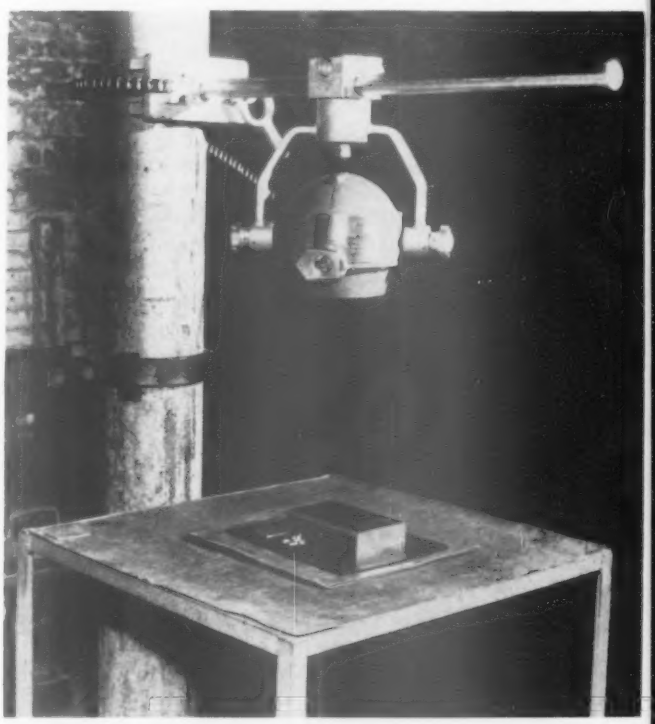


Fig. 9 The gamma-ray projectors may be positioned on lift trucks, suspended by cable from hoists or held in special fixtures as shown

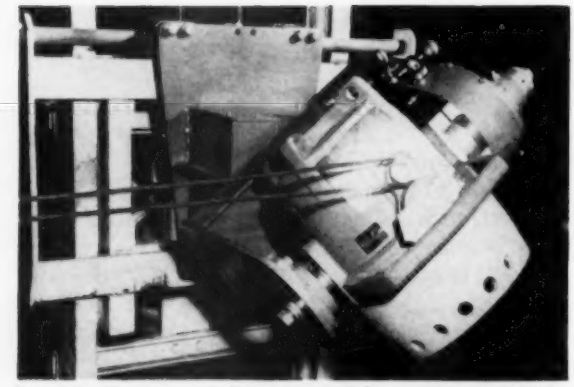


Fig. 10 Shutter may be operated by remote control by means of a rope threaded through pulley on rotor shaft

Fig. 11 Lack of weld penetration in $^1/_2$-in. wall of 24-in. low-alloy steel pipe clearly shows in this radiograph

Energy Commission. The projectors are also safe storage containers for the isotopes when not in use, and do not have to be placed in a concrete vault or other safe to protect individuals in the vicinity. When in operation, they may be turned on and off from a remote location by the use of rope threaded through a pulley located on one end of the rotor shaft (Fig. 10).

A lock is provided to prevent unauthorized use of the instrument. When the projector is turned to the "Off" position, it is automatically locked and can be released only by turning the key in the lock and rotating the shaft.

Applications in Welding

Radiographic testing of welds is frequently the only way to assure safe, dependable performance of process piping or equipment subjected to high pressures or temperatures.

A small size gamma projector is an especially economical means of inspecting repairs to pipe-line welds. These spot shots of repairs are often widely scattered, and the extreme portability of the projector makes it easy to carry it to the different locations and make the necessary exposures.

For spot shots on circumferential welds, the projector in its fixture is on one side of the pipe and the film and weld being radiographed are on the other side. The weld on the near side will not register; only the weld on the far side appears on the image.

When radiographing pressure vessels, tanks, and large diameter piping, the projector is placed inside the work and either spot or panoramic exposures are made. With the larger projectors, butt welds in tanks and pressure vessels of large diameter can easily be radiographed at one exposure.

The defects that are caused by faulty welding techniques may be readily recognized by their characteristic outlines. Porosity is observed on the radiograph as dark spots characterized by their circular shape. These are the spots due to gases entrapped in the weld metal. Straight, thin dark lines of varying length normally indicate lack of fusion—the result of failure to fuse either adjacent layers of weld metal or the weld and the base metal. Cracks appear as dark, wavy lines in contrast to the rather straight lines indicating lack of fusion. Entrapped slag is of lesser density than the weld metal and will therefore produce a darker image. It is usually elongated in appearance—generally in the same direction in which the weld was made. It has a broader outline than a crack or lack of fusion, and is not as dark as gas pockets (Fig. 11).

Regulations and Controls

Because of the hazards associated with radioactive materials, their transportation and use is closely controlled by federal and other regulations. Every user of radioactive material must comply with all applicable federal, state and local laws, regulations, codes and similar controls.

Authorization of the Atomic Energy Commission is required for the acquisition and use of radioisotopes. Regulations are in force governing permissible levels of radiation, permissible dosages, personnel monitoring and instruction. . . . Special regulations govern care and labeling of shipments of radioactive material. Finally, the Atomic Energy Commission authorizes only those persons or organizations to procure radioisotopes which have trained personnel and adequate radiation safety facilities.

The sources of supply for the gamma-ray projection equipment are prepared to undertake the necessary training of personnel and establishment of suitable safety facilities for those desiring to avail themselves of this method of nondestructive testing.

Summary

By way of summary, it may be pointed out that demand for radiographic inspection of welded joints and castings is steadily increasing in general industrial practice as well as in military specifications. The comparatively low initial cost of the gamma-ray equipment, the ease and convenience of using it and the effective results obtained seem likely to greatly expand the use of gamma radiography in the metal working industry.

Acknowledgment

The author gratefully acknowledges the cooperation received from the ASM Committee on Radiography.

REGULATED AND PROGRAMMED RESISTANCE-WELDING CONTROL SYSTEMS

The development of a new current regulator which can be programmed by a slope control to give a regulated sloped current wave for welding is described by authors

BY C. SINCLAIR AND F. S. PARKER

SYNOPSIS. Previous papers and actual industry experience have demonstrated the value of slope control for welding hot-rolled or galvanized steel. The importance of a current regulator for obtaining consistent welds with varying amounts of these materials in the welder throat has also been shown. In the past these two features were not compatible, as the regulator could only regulate a fixed current, not a sloped current pattern. This paper describes the development of a new current regulator, about to become commercially available, which can be programmed by a slope control to give a regulated slope current wave for welding. In addition, the slope gives more accurate control over the total heat delivered to the weld on short weld times where regulator response time becomes significant. The conclusion is that slope control should be applied to either current or voltage regulators if it would normally be used for the material involved and in addition it should be automatically applied with current regulators used on spot welders or seam welders running a definite heat-cool pattern rather than continuous heat on all ferrous metals.

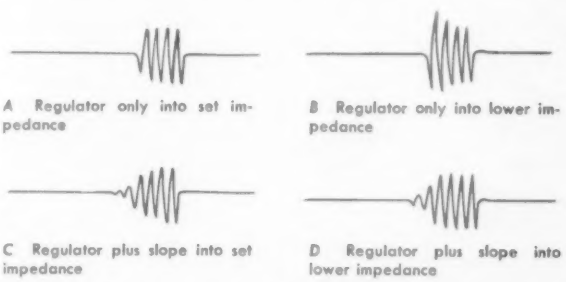
The Problem

The importance of a current regulator to obtain consistent welds when consecutive welds would be made with varying amounts of magnetic material in the throat of the welding machine was established over 12 years ago.[1] The need for a regulator under these conditions comes from the fact that the best unregulated control can only supply an accurately fixed voltage of predetermined magnitude to the welding transformer. However, the current in the weld is the quotient of this voltage divided by the reflected secondary impedance of the welder. The secondary circuit of the welder acts like a one-turn air-core inductance if no magnetic material is present in the throat. Introduction of magnetic material in the throat (usually the material being welded is the magnetic material involved) distorts the flux pattern and changes the impedance which in turn determines the welding current. If the work is shifted to make several welds, a different current is obtained for each weld, depending upon the varying influence of the work on the magnetic field.

Several papers have been written bringing out the advantage of using a slope current wave for welding hot-rolled steel, where surface scale presents an initial high resistance to the current and causes spitting at the tips when passing sufficient current for proper welding of the base metal, or where metals with a lower melting point must first be burned off as in welding galvanized material

It was felt that the design of a new current regulator should make possible the addition of slope control so that a current wave of the desired shape could be obtained, even on welding jobs requiring a regulator to obtain consistent total heat.

Development of such a system also served to minimize one of the inherent limitations of any current regulator system. No current regulator can possibly detect the impedance in the secondary circuit of the welder until current starts to flow. The only solution is to set the regulator to start firing at a fixed voltage which represents an average of the voltages necessary to produce the correct current under the various impedance conditions and then, after current has started to flow, the regulator can determine the error and correct for it. This correction takes about three cycles so on weld times under six cycles with an unsloped wave, the variable portion while the regulator is making its correction becomes a large enough part of the total heat input to produce a significant variation in welds. When a regulator is making a programmed wave where the first few cycles are programmed low enough that their contribution to the total heat is relatively minor, the regulator is given a chance to detect the impedance of the particular weld and correct for it before increasing



A Regulator only into set impedance

B Regulator only into lower impedance

C Regulator plus slope into set impedance

D Regulator plus slope into lower impedance

Fig. 1 Effect of slope control in reducing initial disturbance due to variable load impedance with current regulator

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Presented at 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8–12.

the current to the desired welding value, entirely under control of the regulator.

The actual effect of this is shown in Fig. 1. Figure 1*A* shows the regulator alone controlling the current with the load corresponding to the impedance for which the regulator has been set. Figure 1*B* shows what happens when the load impedance is reduced without changing the regulator adjustment. Figure 1*C* shows the same regulator with slope control added firing into the same load as used in Fig. 1*A*, and Fig. 1*D* shows the corresponding change in current when the load is reduced to that used for Fig. 1*B*. The high initial surge of Fig. 1*B* represents a serious deviation from the total heat input of Fig. 1*A*. The ratio for initial currents between Figs. 1*C* and 1*D* is comparable to that between Figs. 1*A* and 1*B*, but the greatly reduced magnitude of the initial current makes the total heat input much more nearly constant.

The Solution

The solution to the problem was seen to be the development of a set of equipments having compatible inputs and outputs so that they would be cascaded when desired. The basic heat control uses a resistance-capacitance phase-shift network to determine the voltage which will be applied to the welding transformer. The resistance part of this network is a rheostat which can be varied by hand to select the desired heat. This rheostat can be replaced by an electronic equivalent: a vacuum tube, the plate resistance of which can be varied as desired by changing the bias placed on its grids. A complete line of accessory panels including both current regulator and slope controls has been designed using this tube for their output. In addition, the voltage and current regulators were designed to that they could be programmed by means of a variation of resistance, this variation of resistance being supplied by a slope control. This permits the welding current to be both programmed and regulated.

For those not familiar with closed loop regulators, the following applies to any form of closed loop system. First of all, the regulator must have a reference representing the desired magnitude of the quantity being regulated. Second, it must have a feedback signal proportional to the actual quantity being regulated. Third, it must have a circuit to compare these two signals and call for an increase in the regulated quantity, if the feedback signal is less than the reference signal, or for a decrease in the regulated quantity, if the feedback signal is greater than the reference. Then it must have an amplifier to amplify this small difference or error signal to sufficient magnitude to produce the necessary correction in the regulated quantity. In this current regulator, the reference and feedback signals are d-c voltages: the reference obtained from a potentiometer connected across a supply of regulated d-c voltage and the feedback signal obtained by rectifying the output of a wave-shaping circuit which is supplied through a current transformer in series with the welding transformer. The wave-shaping circuit converts the incoming current to a triangular wave-shape which makes the rectified voltage proportional to the rms voltage and current. The resistance of the slope control is inserted between the end of the reference potentiometer representing maximum current and the supply bus. When the slope control calls for maximum current by reducing its resistance to a minimum, the reference potentiometer has its maximum range. When the slope control inserts resistance to call for reduced current, this is just as if a series resistor had been inserted between the reference potentiometer and the voltage supply. This reduces the voltage across the potentiometer and thus the reference voltage obtained at any point on the potentiometer. Since a lower feedback signal, representing a lower current, is required to balance the lower reference voltage, the slope control is able to reduce the output current by increasing its resistance, just as if it were working directly into the heat control phase-shift network (see Fig. 2).

A block diagram of the system is shown in Fig. 3. This shows all of the regulating loops involved. When the sequence panel shuts off the ignitron contactor com-

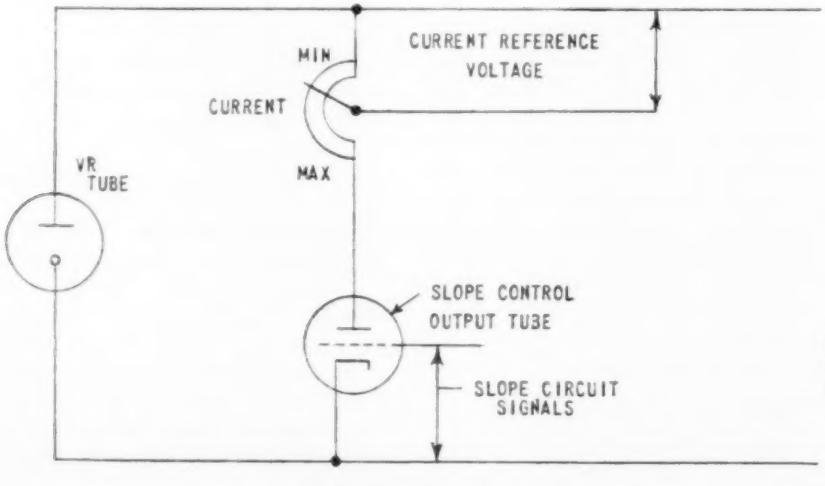

Fig. 2 Slope control of regulator reference

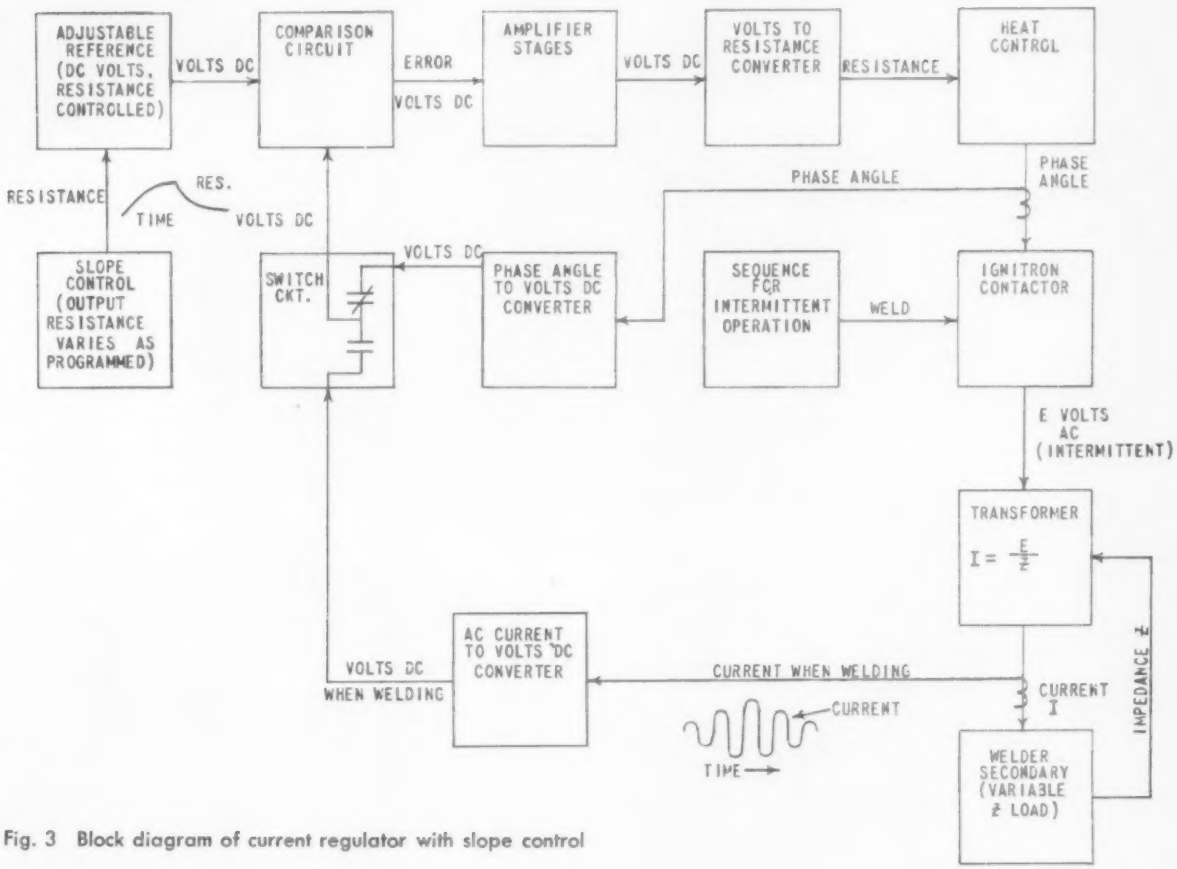

Fig. 3 Block diagram of current regulator with slope control

pletely during the period when no welding is being done, a second regulating loop is necessary. If the comparison circuit continued to look at current and compare that with the reference, it would find a large error on the low side and attempt to phase the heat control on to compensate for this error. Getting no response in the form of increased current, it would drive the heat control to full-phase which corresponds to maximum current and hold it there until the first half-cycle of the next weld had been fired at full heat at which time the regulator would discover its error. To prevent this, a second regulating loop is provided to represent phase-angle in terms of a voltage. A switching circuit switches the feedback side of the comparison circuit over to look at this phase-angle feedback rather than the current feedback when no current signal at all is present. As soon as a current signal of any magnitude at all is obtained, the switching circuit switches back to the current signal. In the block diagram this is represented as a relay, but in the actual equipment it is an all electronic circuit. Since for any one impedance in the welder secondary there will be a definite relation between phase angle and current, by causing the regulator to regulate phase angle until it has a current to regulate, it can be made to fire the first half cycle of a weld at the correct current for one value of welder secondary impedance. The value of impedance for which the current will be started at the correct value can be selected by varying the relationship between phase-angle and output volts of the phase-angle to volts d-c converter.

As was pointed out earlier, but is shown by this block diagram, the heat control tells the ignitron contactor what phase angle to fire at. The ignitron contactor then applies the corresponding voltage to the welding transformer which then draws whatever current is necessary to satisfy the relation I equals E/Z with the impedance term, Z, being determined by the welder secondary. The Z term does not exist in measurable form until current flows so phase-angle is the nearest thing to current which can be regulated until the weld has started.

The same system of using a slope control to program a regulator has also been applied to a new voltage regulator which has been developed. The voltage regulator is a somewhat simpler regulator which compensates for changes in line voltage but not for changes in welder secondary impedance. This is done by running a dummy contactor in miniature at the same phase angle as the real contactor, but the dummy contactor runs continuously and the regulator holds its output constant, despite changes in line voltage. The dummy contactor consists of one 6SN7 tube with its grids greatly overdriven, and reduced line voltage on its anodes.

Reference

1. Cooper, B., "Better Welds Through Regulated Welding Current," The Welding Journal, **23** (1) 5–10 (1944).

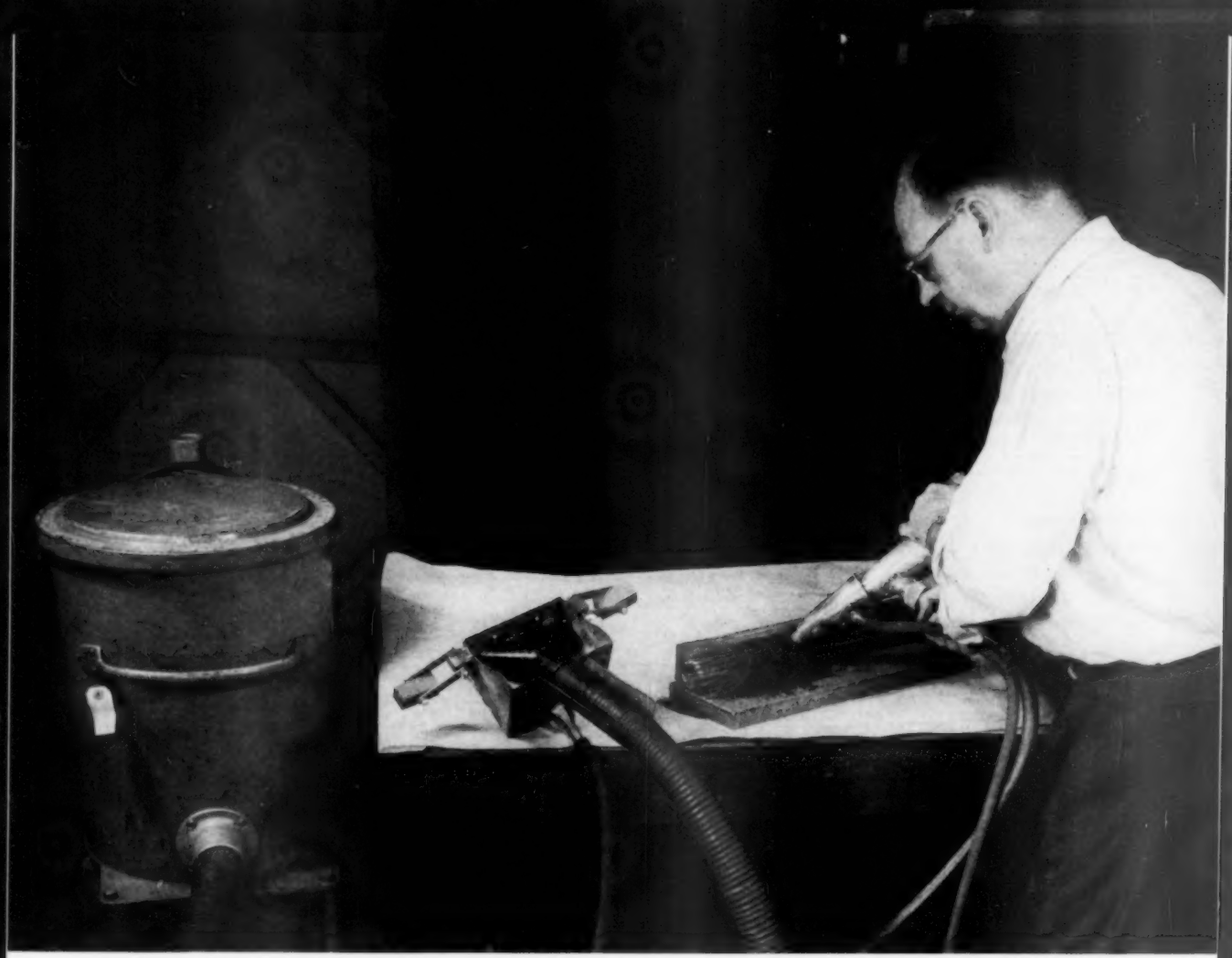

Fig. 1 Typical flexible-electrode submerged-arc welding application with flux fumes pickup attachment in operation

DEVELOPED PROCEDURES FOR THE FLEXIBLE-ELECTRODE SUBMERGED-ARC WELDING PROCESS

Printed procedures used at the welding station, together with accurate metering on the welder, produce maximum metal deposit on as-received material

BY M. H. FRITSCHE

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Presented at 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8–12.

ABSTRACT. Many procedure recommendations for the flexible-electrode submerged-arc welding (FESAW) process call for direct current-reverse polarity with its resultant deep penetration characteristics. When *direct current-straight polarity* is used, a slight sacrifice in penetration occurs, however, 56% more filler metal per unit time can be deposited; stronger but smaller size "equivalent strength" fillet welds using less filler metal can be specified. This controlled "equivalent strength" fillet weld is stronger than a weld deposited with Type E-6012 manual-arc mild-steel welding electrodes.

To accomplish the controlled "equivalent strength" fillet weld, the operator must follow a carefully developed procedure and proper metering must be provided on his welding equipment.

Flux compositions influence the rate of metal deposit and the

mechanical properties of the weld metal. Selection of the proper welding flux and wire is important.

Operator comfort is also a prime consideration. Operator fatigue is minimized when a drag-welding technique is practiced; a small lip on the cone tip of the flux can make this possible. If fumes generated by welding "as-received" material becomes a "nuisance factor" to the welding operator, a flux-fumes pickup attachment will add to his comfort.

By assigning several flexible-electrode submerged-arc welding machines to large weldments and welding these units nonpositioned, distortion control of the weldment is accomplished; also, a greater volume of tonnage is realized.

All procedure recommendations made in this paper have been "time tested" under production fabrication conditions and are considered practical.

History

Between the years 1925 and 1928, automatic welding began to be used in industry. The first applications used bare or lightly-coated wire. From this period to 1935, many systems of automatic welding were promoted. In 1935, a submerged-arc process using prefused flux came into prominence. In 1937, the first application of submerged-arc welding made its appearance in the Pittsburgh, Pa., district. The evolution from submerged-arc welding into flexible-electrode submerged-arc welding required the development of lighter controls, as well as lighter wire-feeding mechanism.

In 1944, approximately, a prominent manufacturer of submerged-arc welding fluxes and equipment introduced a hand welder. The rate of filler-rod deposit and the direction of the weld was controlled entirely by hand, a voltmeter attached to the welding nozzle being the only guide to welding control. Manually-deposited granular flux covered the welding arc. The equipment was designed particularly for repairing welds, casting defects and for making plug welds. Welding rods $^1/_4$ to $^1/_2$ in. in diameter supplied in 16 ft lengths were cut in half for use in this hand welding unit. Operator skill was most important in this early type of hand welder. In 1946 or 1947, approximately, equipment for the flexible-electrode submerged-arc welding process, as we know it today, became prominent.

Early in the history of this new process, one manufacturer chose to load the flux in a container at the arc end of the electrode. A second manufacturer loaded the flux in a pressure vessel at the wire reel end of the electrode and transported the flux by air pressure to the arc end. The second manufacturer has now abandoned this and is also loading the flux in a container at the arc end of the electrode.

Figures 1 and 2 picture a typical flexible-electrode submerged-arc welding unit.

Operating Necessities

Flexible-Electrode Submerged-Arc Welding Equipment

There are basic requirements for the wire drive and control unit used for flexible-electrode submerged-arc welding. A voltmeter and an ammeter are a necessity. It is impossible to follow a given procedure without these meters.

The operating arc-voltage variation must be kept between plus and minus 2 volts. A greater variation would create too much change in the size and shape of the weld bead; also, it would cause too much change in the depth of penetration into the base metal. Therefore, the welding operator must adjust his machine occasionally to maintain uniform metal deposit. As shown in Fig. 2, the meters are best placed on the wire drive unit. The wire drive unit is located 12 to 14 ft from the operator, since the wire feed conductor cable assembly is that long.

A 600-amp rectified d-c arc-welding machine is recommended to supply straight-polarity welding current. When adjusting the weld current, an extension cord with a remote control switch should be within convenient reach of the operator.

Flexible-Electrode Submerged-Arc Welding-Equipment Maintenance and Operation

It is very important that accumulations of dirt and metal slivers in the conductor cable assembly connected to the wire drive unit be removed at every wire reel change. The most efficient means of accomplishing this is to have a spare conductor cable assembly cleaned and ready to replace the used cable when a new reel of wire is placed in the machine. Compressed air blown through the conductor cable after its removal

Fig. 2 A typical flexible-electrode submerged-arc welding wire drive unit with voltmeter, ammeter, procedure page and a flux-fumes pickup attachment

from the wire drive unit is required to take out the dirt particles.

Before threading new wire through the cleaned conductor cable, it is important that the sharp leading edges of the wire be filed off. If these sharp edges are not removed, there is danger of damaging the conductor cable assembly.

After each metal deposit welding cycle, the end of the welding wire should be clipped on an angle to provide a sharp point for better arc starting. The cut edge eliminates any adhering molten slag deposited during a regular "arc stop."

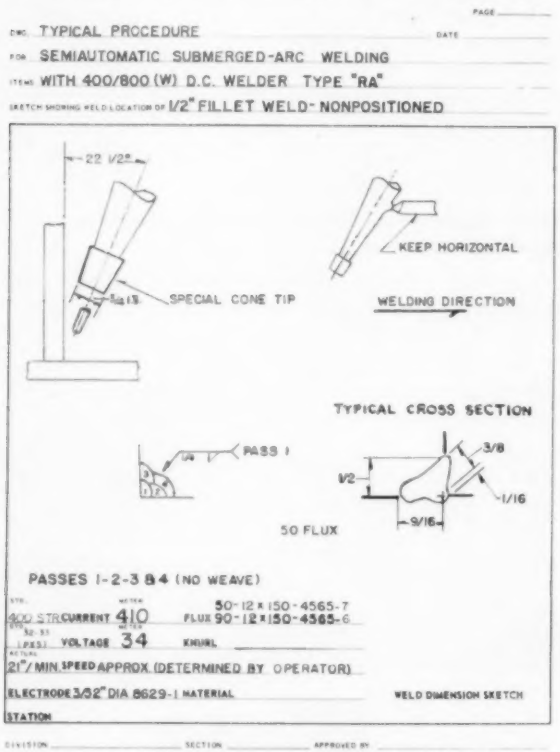

Fig. 3 Typical procedure page for the flexible-electrode submerged-arc welding process. It is usually placed in a transparent plastic envelope in full view of the welding operator

Procedure Pages

When adequate welding equipment is provided, the next step is to develop proper welding procedures for the operator who must use this equipment. A typical procedure is shown in Fig. 3. A summary of developed procedures for fillet weld sizes from $^1/_4$ to 1 in. is arranged in Table 1. These settings are simplified and coordinated. For example, note how the larger-size multiple-pass welds use the same current and speed as the $^1/_4$ and $^3/_8$-in. single-pass fillet, varying the voltage only. *The procedure for a $^3/_8$-in. fillet weld is basic.* It can be readily applied to many types of joints including single-pass and multipass applications.

Maximum metal deposit is obtained with maximum welding current. The procedures of Table 1 were developed for application where maximum welding current will produce an acceptable bead appearance on hot-rolled steel containing normal mill scale.

In the lower left hand corner of a standard blank procedure page, such as Fig. 3, a space is provided on each side of the printed words "Current," "Voltage" and "Speed." The data listed in the blank space to the left should be derived from accurate meter readings and measured distance per unit time. The data marked in the blank space to the right should be derived from the dial settings or meter readings at the production welding station. The figures marked in these right hand spaces should be large and plainly printed.

Speed Calculation

To the right of the word "Speed" on the standard procedure sheet is the notation "Determined by Operator." It is relatively easy for an operator to determine the travel speed required to follow the recommended speed. To determine this welding speed, the following operations should be followed:

(*a*) Measure off an increment of travel lengths.

Table 1—Summary of Semiautomatic Submerged-Arc Welding Fillet-Weld Procedures

Fillet size	*Joint*	*DC (−) Amp*	*DC (−) Volt*	*Flux size, 12 × 150*	*No. of passes*	*Speed, ipm*
$^1/_4$	Positioned	445	34	5 or 9	1	25
$^1/_4$	Nonpositioned	400	33	5 or 9	1	21
$^5/_{16}$	Nonpositioned	400	33–34	5 or 9	1	14
$^3/_8$	Positioned	520	35	5 or 9	1	15
$^3/_8$	Nonpositioned	400	33–34	5 or 9	1	11
$^1/_2$	Positioned	445	34	5 or 9	2	Pass 1@25
		520	39			Pass 2@15
$^1/_2$	Nonpositioned	400	32–33	5 or 9	4	Pass 1–4@21
$^3/_4$	Positioned	520	35	5 or 9	3	Pass 1@15
		520	39			Pass 2–3@12
$^3/_4$	Nonpositioned	400	33–34	5 or 9	7	Pass 1@11
		400	33			Pass 2–7@21
1	Positioned	520	35	5 or 9	5	Pass 1@15
		520	39			Pass 2–4@12
		520	39			Pass 5@10
1	Nonpositioned	400	33–34	5 or 9	10	Pass 1–4@11
		400	33			Pass 5–9@21
		400	33			Pass 10@31

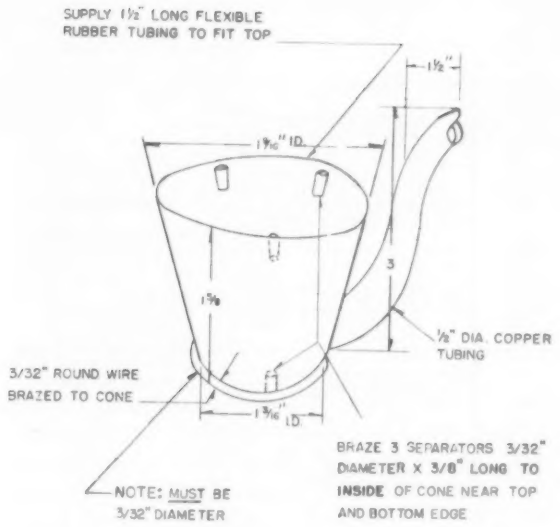
SUPPLY 1½" LONG FLEXIBLE RUBBER TUBING TO FIT TOP
1½"
1⅞" I.D.
3
1⅝
½" DIA. COPPER TUBING
3/32" ROUND WIRE BRAZED TO CONE
1 3/16" I.D.
BRAZE 3 SEPARATORS 3/32" DIAMETER X 3/8" LONG TO INSIDE OF CONE NEAR TOP AND BOTTOM EDGE
NOTE: MUST BE 3/32" DIAMETER

Fig. 4 Fumes collector for flux-fumes pickup attachment. This fits a standard flux can of a flexible-electrode submerged-arc welding unit

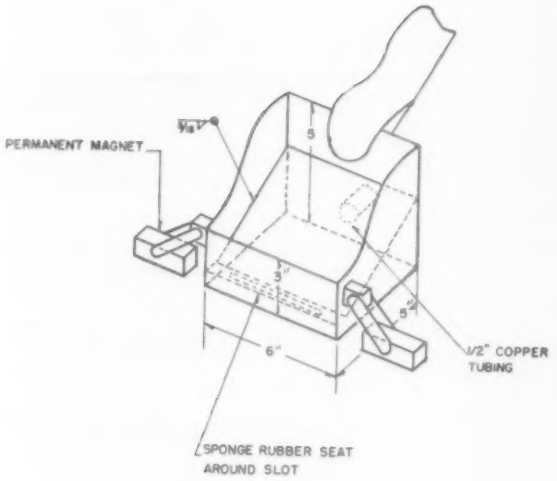

Fig. 5 Pickup tool holder for flux fumes pickup attachment with two adjustable permanent magnet hold-down clamps

For example, if the welding speed is 30 ipm, two marks should be placed $7^1/_2$ in. apart for a 15-sec ($^1/_4$ min) interval.

(*b*) The operator, as he welds, should count mentally one-0-one, one-0-two, etc., to one-0-fifteen, as he would if he were timing for a camera exposure. His speed should be regulated so that he crosses the $7^1/_2$-in. mark as he is counting one-0-fifteen.

Transparent Envelope

One of the advantages of submerged-arc welding is the ease of readily reproducing welds. Procedures carefully developed and plainly exhibited minimize the "human element" factor of flexible-electrode submerged-arc welding.

Printed procedure pages should be issued to the welding operator in a transparent envelope container, which can be placed in a prominent place for reference at the welding station. These envelopes, transparent front and back, are $9^1/_2$ x $12^1/_2$ in.

Ease of operation is also provided when the flux-fumes pickup attachment is used to eliminate the discomfort of welding fumes.

Flux-Fumes Pickup Attachment and Special Cone Tip

When a "fused"-type flux vaporizes and the material being welded is molten, fumes, irritating and somewhat hazardous to the welding operator, are produced. Shown in Figs. 1 and 2 is a flux-fumes pickup attachment for removal of fumes. This attachment (see Fig. 2) consists of two main parts, connected by a $^3/_8$-in. ID flexible rubber hose: (1) the "fumes collector" part attached to the standard conductor cable welding gun assembly; and (2) the "pickup tool holder" part which supports the standard flux pickup tool.

The fumes collector, shown in detail in Fig. 4, is constructed airtight and is attached to a standard welding-gun can. This attachment is open at the bottom only. The air space between the fumes collector cone and the welding-gun can is $^1/_{16}$ in. (The collector cone is made to clear a "special cone tip" having a $^3/_4$-in. ID.)

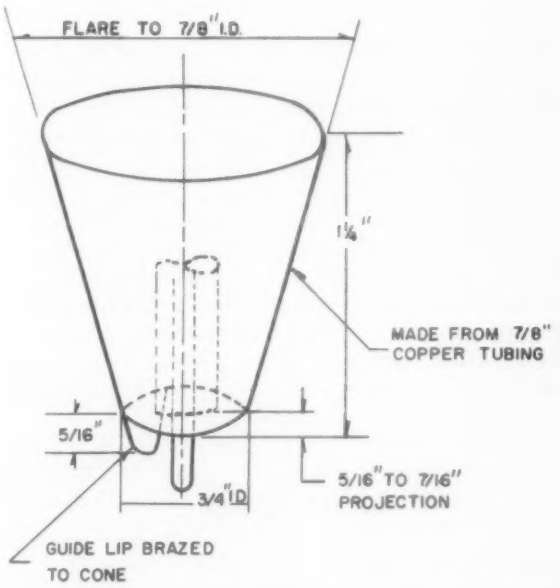

Fig. 6 Special cone tip. The guide lip brazed to the bottom of cone tip makes "drag-technique" welding possible

The pickup tool holder, shown in detail in Fig. 5, is an airtight constructed chamber except for a slot opening surrounded with sponge rubber which contacts by vacuum with the pickup tool. There are two adjustable permanent magnet hold-down clamps attached to the sides. A saddle-handle bracket attached to one end of the holder is used to hold the tool and hose and also as a convenient handle to move the pickup tool holder to within convenient reach of the welding operator. After each welding cycle has been completed,

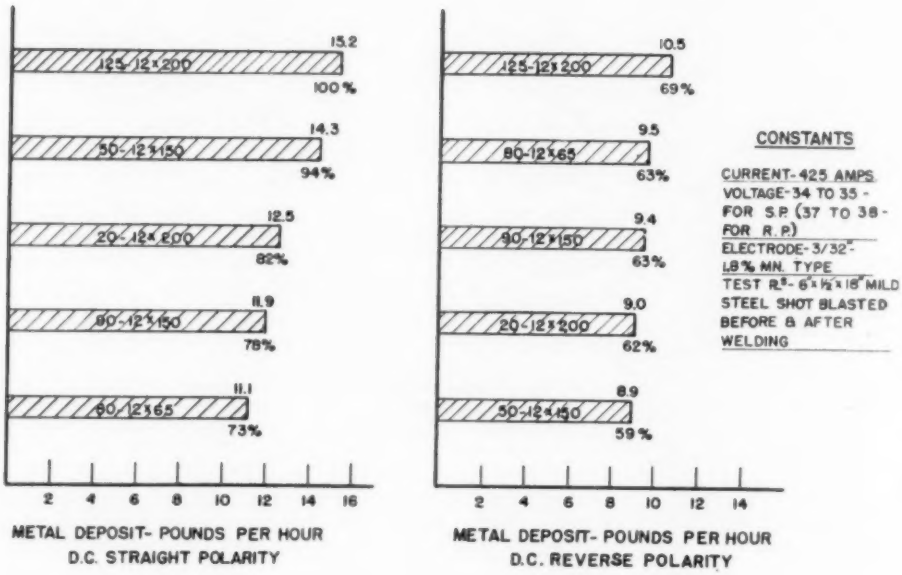

Fig. 7 Metal deposit rates influenced by fused flux grades 12, 5, 2, 9 and 8

the vacuum pickup tool may be removed from the pickup tool holder to recover the unfused flux covering the weld bead. Before welding is continued, the pickup tool is replaced over the slot in the pickup tool holder.

A special copper cone tip, shown in Fig. 6, slightly larger in diameter than a standard tip, is recommended when greater flux coverage is required. This larger diameter tip is required with straight polarity welding because of its higher wire temperature. The lip extension on the bottom of the cone tip helps to reduce operator fatigue by allowing the operator to practice a drag-welding technique and by placing the flux can at the proper height for flux coverage and electrode positioning.

Let us now consider how adequate welding equipment controlled by an operator trained to follow a plainly exhibited procedure page can deposit the maximum amount of weld metal.

Metal Deposition

The Influence of Fluxes on Weld-Metal Deposition

In general, it is important to regulate the depth of flux in submerged-arc welding. A minimum depth of coverage to contain the arc pressure will provide maximum freedom for gas to escape. With higher current, a smaller, more dense grain size flux is required to contain the arc. New flux should be mixed with recovered flux at regular intervals. This is especially important when the "dust" size fluxes are used. Generally, a mixture of 50% new flux with 50% recovered flux is good practice.

Grade 5, a fused type flux currently used, has several important advantages. They are:

(*a*) Exceptional scavenger action for decomposing the oxides. It is far superior to grade 8 in this respect. With grade 8 flux, surface oxides must be cleaned before welding.

(*b*) A high rate of metal deposit. With straight polarity, grade 5 flux is near the top of the list with 14.3 lb per hr deposit rate at 425-amp direct current-straight polarity as compared to 11.1 lb per hr when grade 80 is used (see Fig. 7).

(*c*) An improvement of weld-metal tensile properties as shown in Table 2.

The influence on metal deposit rates of various grades of fused-type flux is compared at 425 amp and

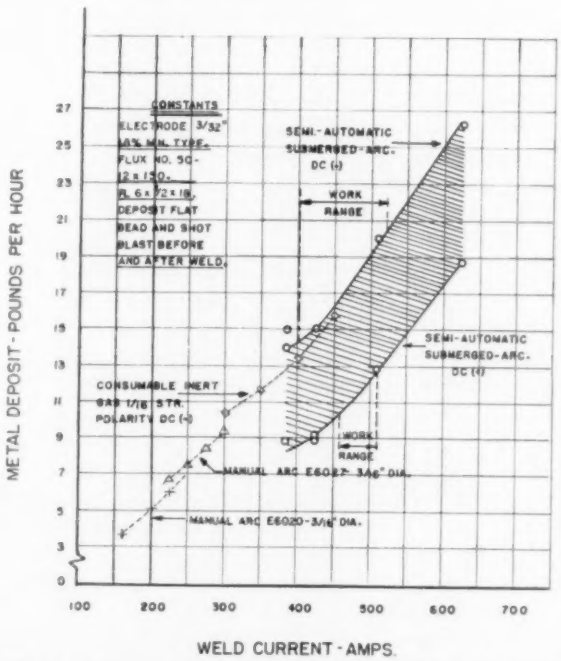

Fig. 8 Weld-metal deposit rate. Maximum metal deposit is realized with the flexible-electrode submerged-arc welding process when direct current, straight polarity is used

Table 2—Influence of Fluxes on Mechanical Properties[1]

Electrode, type 1.8% mn	Fused-flux grade	0.505 All-weld-metal tensile: Yield point, psi	Ultimate strength, psi	Per cent elongation in 2 in.	Reduction in area, %
36	2	51,000	75,500	24.0	43.7
36	5	62,700	87,200	25.3	50.1
36	7	54,500	74,500	29.0	57.3
36	8	56,000	76,000	29.0	59.1
36	9	62,000	81,000	25.0	53.3

shown in Fig. 7. It should be noted that the metal deposit differential is between 11.1 and 15.2 lb per hr (27% variable) when straight polarity is used. With reverse polarity, the difference is between 8.9 and 10.5 lb per hr (10% variable). Also, the different grades of flux are not in the same order for straight and reverse polarity.

Grade 12 flux is a new type of fused flux and preliminary tests have shown a high metal, deposit rate with direct current-straight polarity. More development work will be required, however, before a complete evaluation can be presented.

The Influence of Straight and Reverse Polarity on Weld-Metal Deposition

When direct current-straight polarity welding current is used, 56% more metal can be deposited. Two curves are plotted in Fig. 8 comparing the weld metal deposited with grade 5 flux, size 12 x 150, with a current range between 385 and 625 amp. A $^3/_8$-in. positioned fillet can be welded at 15 ipm at 520-amp direct current-straight polarity and 35 volts. To weld the same size fillet with direct current-reverse polarity, a speed of only 11 ipm can be attained.

The deposition rates for all the curves shown in Fig. 8 were derived from test samples made in our investigation. Weld-metal deposits made on mild-steel test plates 6 x $^1/_2$ x 18 in., were weighed before and after welding to determine the weight of metal deposited. The arc time was derived with a stop watch. The total welding-time interval varied from $1^3/_4$ to $2^1/_2$ min, depending upon the rate of metal deposited. The test plates were shot blasted before welding and again lightly blasted after welding to remove all foreign nonmetallic elements.

Typical Fillet-Weld Cross Sections

In Fig. 9 are shown a representative number of samples of fillet welds cross sectioned perpendicular to the direction of welding. Cross sections B10, B12, and B14 were welded nonpositioned. When the work is positioned, higher welding current can be used, thereby increasing the metal-deposit rate. For example, B14, a 1-in. fillet requires 10 passes nonpositioned, and B4z, the same size weld, is made in five passes positioned.

Since the cost of *positioning* large weldments must be considered, it is often possible to assign more welders to a nonpositioned heavy section, thereby balancing the *distortion* factor in the weldment and reducing weldment cost.

When welding equipment is provided with proper meters, and a procedure is exhibited to guide a competent welding operator, the "equivalent-strength

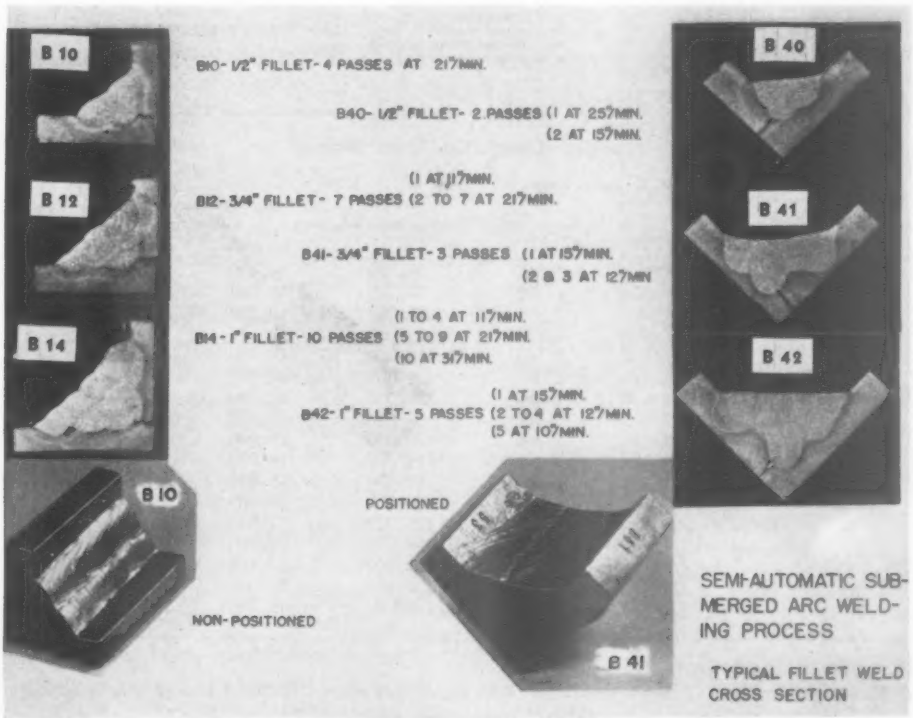
B 10
B10- 1/2" FILLET- 4 PASSES AT 21"/MIN.
B40- 1/2" FILLET- 2 PASSES (1 AT 25"/MIN.
(2 AT 15"/MIN.
B 40
(1 AT 11"/MIN.
B 12
B12- 3/4" FILLET- 7 PASSES (2 TO 7 AT 21"/MIN.
B41- 3/4" FILLET- 3 PASSES (1 AT 15"/MIN.
(2 & 3 AT 12"/MIN
B 41
(1 TO 4 AT 11"/MIN.
B 14
B14- 1" FILLET- 10 PASSES (5 TO 9 AT 21"/MIN.
(10 AT 34"/MIN.
B 42
(1 AT 15"/MIN.
B42- 1" FILLET- 5 PASSES (2 TO 4 AT 12"/MIN.
(5 AT 10"/MIN.
B 10
POSITIONED
NON-POSITIONED
B 41
SEMI-AUTOMATIC SUBMERGED ARC WELDING PROCESS
TYPICAL FILLET WELD CROSS SECTION

Fig. 9 Typical fillet-weld cross sections welded by the flexible-electrode submerged-arc welding process

fillet weld" can be specified in the welding design standards. This means that the size of all fillet welds $^3/_8$ in. and larger can be reduced $^1/_{16}$ in. with a resulting saving in filler metal of 7.4 lb per 100 ft of weld seam. When a 1-in. fillet weld is reduced $^1/_{16}$ in., the filler metal saved is 30.8 lb per 100 ft of weld seam.

Economic Benefits

Equivalent-Strength Fillet Welds

A program permitting the use of the equivalent-strength fillet weld would reduce production costs considerably when the flexible-electrode submerged-arc welding process is used as a method of metals joining.

Physical tests have shown that fillets made by this process may be reduced $^1/_{16}$ from nominal size for manual welds, *and that a $^5/_{16}$-in. fillet weld made with direct current-straight polarity is stronger than a $^3/_8$-in. manual fillet.* These tests were run to compare the strength of a $^3/_8$-in. fillet (manual arc) welded with Type E-6012 electrodes with a $^5/_{16}$-in. fillet weld made by the flexible-electrode submerged-arc process using direct current-straight polarity and following our standard developed procedure for a $^5/_{16}$-in. fillet (see Table 1 and Fig. 3.) Figures 10 and 11 show this comparison in bar-graph form, and Tables 3 and 4 give detail data.

There are two series of tests involved, longitudinal shear strength and transverse shear strength.

(*a*) The shear strengths listed in the AWS HANDBOOK[2] are lower than those given in Tables 3 and 4. The HANDBOOK results, however, are based on the vertical leg measurement of a fillet weld only to determine the size even if the horizontal leg is less than that size. Our standard developed procedures for these tests are based on vertical and horizontal leg measurement to determine the fillet-weld size.[3]

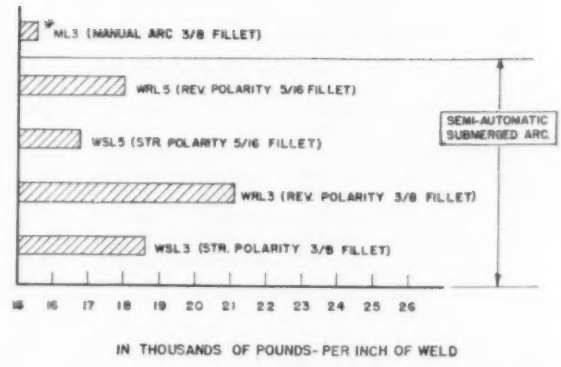
*ML3 (MANUAL ARC 3/8 FILLET)
WRL5 (REV. POLARITY 5/16 FILLET)
WSL5 (STR. POLARITY 5/16 FILLET)
WRL3 (REV. POLARITY 3/8 FILLET)
WSL3 (STR. POLARITY 3/8 FILLET)
SEMI-AUTOMATIC SUBMERGED ARC
15 16 17 18 19 20 21 22 23 24 25 26
IN THOUSANDS OF POUNDS-PER INCH OF WELD
* KEY TO MARKING SYSTEM
M = MANUAL ARC WELDING
T = TRANSVERSE FILLET
W = FESAW PROCESS
R = REVERSE POLARITY
S = STRAIGHT POLARITY

Fig. 10 Longitudinal shear strengths of $^5/_{16}$-in. and $^3/_8$-in. fillets for equivalent strength evaluation of the flexible-electrode submerged-arc welding process

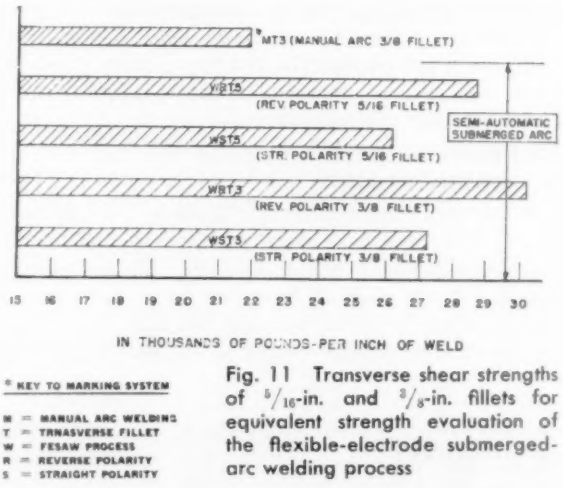
*MT3 (MANUAL ARC 3/8 FILLET)
WST5 (REV. POLARITY 5/16 FILLET)
WST5 (STR. POLARITY 5/16 FILLET)
WRT3 (REV. POLARITY 3/8 FILLET)
WST3 (STR. POLARITY 3/8 FILLET)
SEMI-AUTOMATIC SUBMERGED ARC
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
IN THOUSANDS OF POUNDS-PER INCH OF WELD
* KEY TO MARKING SYSTEM
M = MANUAL ARC WELDING
T = TRNASVERSE FILLET
W = FESAW PROCESS
R = REVERSE POLARITY
S = STRAIGHT POLARITY

Fig. 11 Transverse shear strengths of $^5/_{16}$-in. and $^3/_8$-in. fillets for equivalent strength evaluation of the flexible-electrode submerged-arc welding process

Table 3—Equivalent Fillet Samples—Longitudinal Shear Strength

Tension tests

	Length of fractured fillet, in.					Fillet load, lb/lin. in.	
*Mark**	*F1*	*F2*	*F3*	*F4*	*Fracture load, lb*	*Separate*	*Average*
8-ML-3A	1.492	1.493	1.484	1.491	98,000	16,400	
8-Ml-3B	1.495	1.506	1.479	1.492	89,500	15,000	
8-ML-3C	1.489	1.490	1.493	1.496	91,500	15,300	15,500
13-WRL-5A	1.479	1.484	1.485	1.479	104,000	17,500	
13-WRL-5B	1.461	1.486	1.497	1.503	110,000	18,500	18,000
14-WSL-5A	1.488	1.485	1.497	1.489	101,000	16,900	
14-WSL-5B	1.464	1.492	1.483	1.480	98,000	16,600	16,700
14-WSL-5C	1.487	1.492	1.491	1.486	94,000	15,800	
14-WSL-5D	1.524	1.490	1.492	1.476	90,000	15,000	15,400
14-WSL-5E	1.499	1.443	1.529	1.469	112,500	18,900	
14-WSL-5F	1.484	1.486	1.484	1.483	110,500	18,600	
14-WSL-5G	1.492	1.499	1.488	1.489	108,500	18,200	
14-WSL-5H	1.494	1.487	1.496	1.481	106,250	17,800	18,400
9-WRL-3A	1.485	1.491	1.496	1.478	119,000	20,000	
9-WRL-3B	...	...	...	...	132,000	22,300	21,100
10-WSL-3A	1.464	1.500	1.492	1.480	108,500	18,300	
10-WSL-3B	1.485	1.490	1.484	1.496	113,000	19,000	18,600

NOTE: Fracture location on all samples was at the weld.

* *Key to marking system:* M, manual-arc welding; L, longitudinal fillet; W, FESAW procedures; R, direct current-reverse polarity; S, direct current-straight polarity; T, transverse fillet; and 3 and 5 (suffix), $^3/_8$ and $^5/_{16}$ fillet, respectively.

Table 4
Equivalent Fillet Samples—Transverse Shear Strength

Tension tests

Mark*	Width, in.	Breaking load, lb	Fracture area	Fillet load lb/lin in. Separate	Fillet load lb/lin in. Average
7-MT-3A	1.502	70,000	Weld	23,300	
7-MT-3B	1.517	66,000	Weld	21,800	
7-MT-3C	1.510	62,000	Weld	20,500	21,900
5-WRT-5A	1.516	85,000	Weld	28,000	
5-WRT-5B	1.515	88,500	Weld	29,200	28,600
6-WST-5A	1.508	77,000	Weld	25,500	
6-WST-5B	1.525	82,000	Weld	26,800	26,100
6-WST-5C	1.500	69,500	Plate	23,200	
6-WST-5D	1.510	62,000	Weld	20,500	21,800
6-WST-5E	1.512	78,000	Weld	25,800	
6-WST-5F	1.523	84,500	Weld	27,700	
6-WST-5G	1.505	81,000	Weld	26,900	
6-WST-5H	1.511	81,000	Weld	26,800	26,800
1-WRT-3A	1.517	92,500	Weld	30,500	
1-WRT-3B	1.514	90,000	Weld	29,700	30,100
2-WST-3A	1.515	81,500	Weld	26,900	
2-WST-3B	1.495	82,500	Weld	27,600	27,200

NOTE: Fracture location on all samples was at the weld.

* *Key to marking system:* M, manual-arc welding; L, longitudinal fillet; W, FESAW procedures; R, direct current-reverse polarity; S, direct current-straight polarity; and T, transverse fillet; and 3 and 5 (suffix), $^3/_8$ and $^5/_{16}$ fillet, respectively.

Table 5—Filler-Metal Comparison of Three Manual-Guided Welding Processes

Process	Electrode	Deposition rate, lb/hr	Welding current, amp
Flexible-electrode submerged-arc	$^3/_{32}$ in. diam, 1.8% Mn type	19.9*	520 max, dc (−)
Consumable-electrode, inert-gas	$^1/_{16}$-in. straight polarity	15.8*	450 max, dc (−)
Manual-arc	$^3/_{16}$-in. E6027 type	7.24†	210–270, ac
Manual-arc	$^3/_{16}$-in. E6020 type	4.94†	150–225, ac

* Maximum current.
† Average current.

(*b*) The AWS HANDBOOK[3] was followed for regulations governing the way shearing strength shall be determined.

(*c*) The AWS HANDBOOK[4] was used as a guide for preparing the material for the test specimens. The test material was 4-in. wide x 1-in. thick mild steel.

(*d*) For strength requirements the AWS HANDBOOK[5] was followed. Figure 12 shows typical fractured transverse and longitudinal specimens, and Fig. 13 shows how the speed variable was controlled in welding the test samples.

Since there has been considerable emphasis placed on the advantages of flexible-electrode submerged-arc welding, it might be well to compare this process with other manual-guided welding processes.

Comparison of Three Manual-Guided Processes

Three manual-guided welding processes to be compared are: flexible-electrode submerged-arc, consumable-electrode inert-gas, and powdered-iron manual-arc processes. It is difficult to establish a realistic comparison of these three processes. Submerged-arc process involves granular flux and the recovery of fused and unfused flux. Consumable-electrode inert-

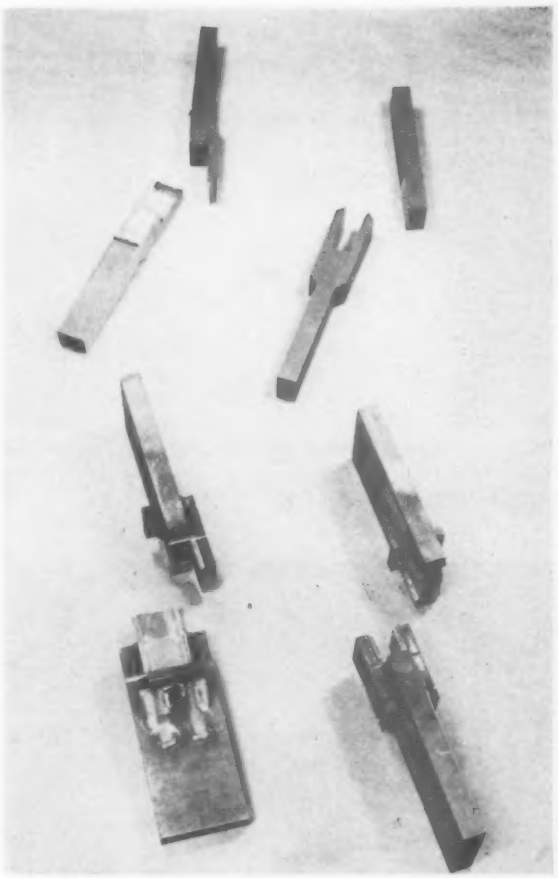

Fig. 12 Typical fractured transverse-shear and longitudinal-shear test specimens. Standard AWS procedures

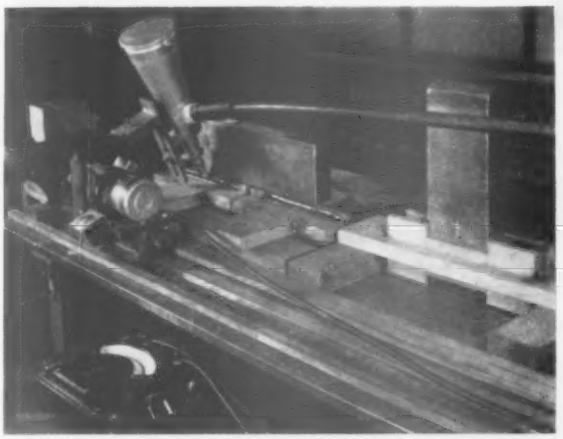

Fig. 13 Test setup for welding transverse and longitudinal-shear test specimens. Standard AWS procedures. The travel speed of the electrode is mechanically guided and regulated

Fig. 14 Bracket arm for a vertical water-wheel generator. By assigning several flexible-electrode welders to large weldments, distortion can be controlled

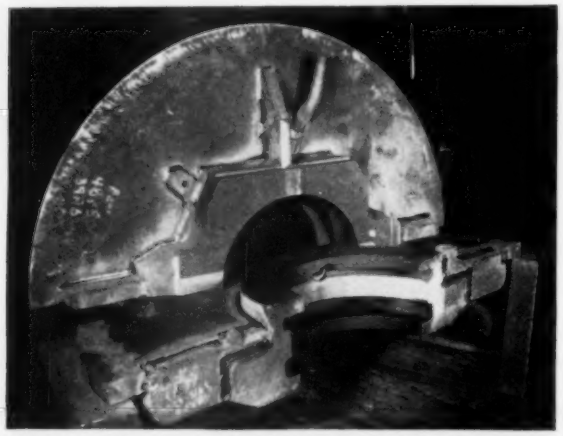

Fig. 15 Bearing bracket for hydrogen-cooled turbo generator. Irregular welds for flexible-electrode applications

gas process requires no cleaning time after the weld metal has been deposited, but the cost of argon inert gas is high and the small-diameter wire electrode required for this process is usually more expensive than the larger diameter wire used with the other two processes. Powdered-iron manual-arc process involves slag and spatter removal after welding.

The comparison shown in Table 5 is a measure of metal deposition only. The amount of weld metal deposited is directly proportional to the welding current. Optimum welding procedures were used to compile the data used in this comparison. Weld-metal deposits were made on mild-steel test plates 6 x $^1/_2$ x 18 in. These plates were shot blasted before welding to remove all surface oxides; they were then weighed. After welding, the plates were again lightly shot blasted to remove all traces of residual flux. They were again weighed to determine the amount of metal deposited. The same arrangement was followed for each one of the three processes in the comparison.

A factor which includes cleaning time, welding-rod cost, argon-inert-gas cost and other items must be added to level this comparison. This factor will vary with conditions established at the manufacturing section involved.

Figure 8 gives a series of curves showing the complete range of metal-deposit rates for three manual-guided welding processes. There is a degree of overlapping of one process into the other.

Applications

In one of our heavy fabrication plants, it is more economical to weld large water wheel spider arms by the flexible-electrode submerged-arc process. Figure 14 is an illustration of one of these arms. By assigning several welding outfits and using them simultaneously on large weldments, harmful distortion can be controlled without the use of a positioner.

A more complicated weldment such as the bearing bracket shown in Fig. 15, is mounted on a welding positioner. The irregular seams on this type of weldment are easily welded with a flexible-electrode submerged-arc machine.

Conclusions

1. With flexible-electrode submerged-arc welding, maximum metal is deposited when direct current-straight polarity is used. Over 50% more metal can be deposited with straight polarity than with reverse polarity.

2. A voltmeter and an ammeter are essential instruments and should be mounted on the wire drive unit. Arc voltage cannot vary more than ±2 volts.

3. Accurately-developed procedures should be displayed in a transparent envelope in full view of the operator. With procedure pages, operator training is simplified.

4. The procedure for a $^3/_8$-in. fillet weld can be readily applied to many types of joints.

5. Equivalent strength fillet welds are stronger than larger manual-arc welds. A saving of 30 lb of filler metal is possible for each 100 ft of 1-in. fillet weld.

6. Operator fatigue is reduced by using a drag-technique system. A flux-fumes pickup attachment will eliminate annoying fumes when "as-received" material is welded.

7. Proper welding flux selection increases the metal-deposit rate.

8. Distortion in large weldments can be controlled by using several flexible-electrode submerged-arc machines simultaneously on the same weldment. The welds are made with the weldment nonpositioned.

Ackowledgment

The author wishes to thank Westinghouse Headquarters Metals Joining Development Laboratory for permission to publish this paper.

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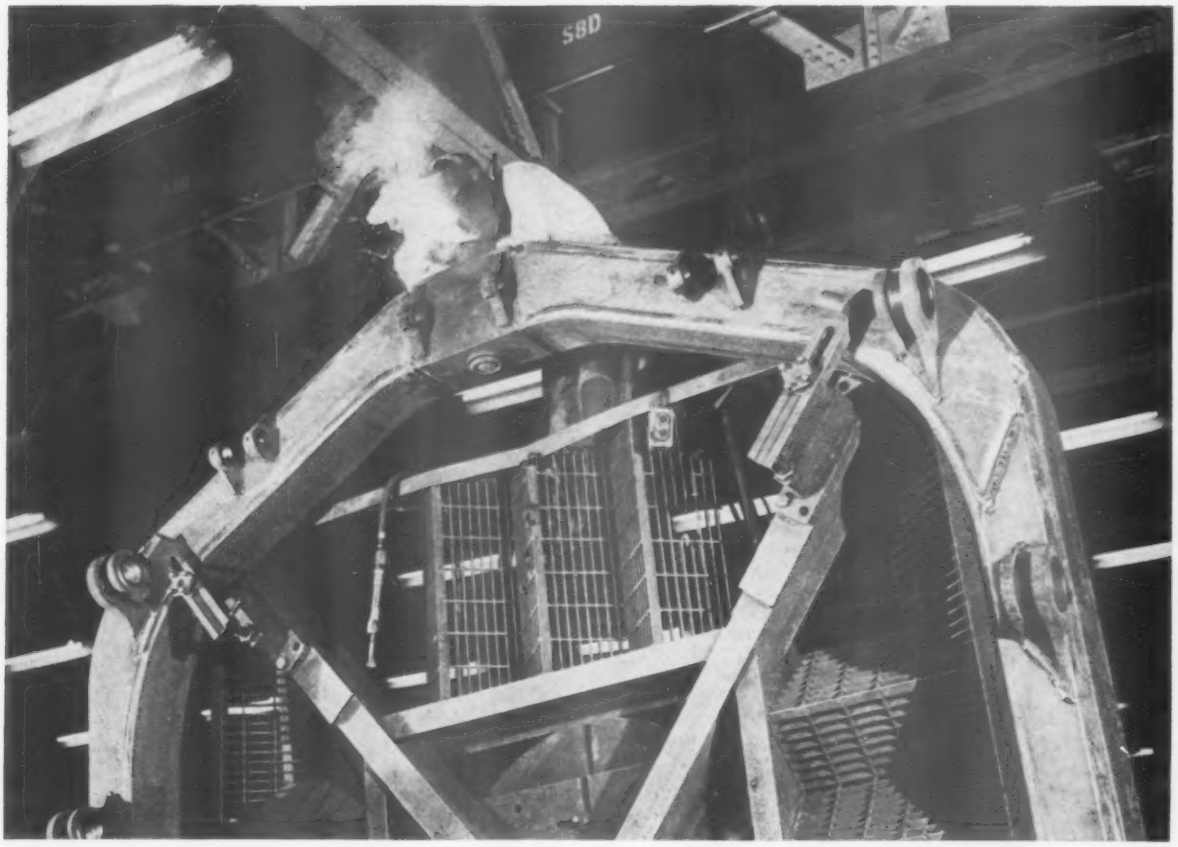

The "C" frame used to attach the bulldozer blade to a Caterpillar tractor is shown here mounted in the welding positioner. The operator is joining the front of the center bracket using the magnetic-flux gas-shielded arc-welding process. In this picture the operator is about 15 ft above the floor

MANUAL MAGNETIC-FLUX GAS-SHIELDED ARC WELDING OF MILD STEEL

Newly developed process described by authors as being capable of producing high-quality welds in mild steel in all positions at greater welding speeds and lower welding cost than covered electrodes

BY N. DAVIS AND R. T. TELFORD

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Introduction

During the last 25 years, many advances have been made in the art of welding mild steel. New processes, such as submerged-arc and inert-gas welding, have been developed and widely exploited by industry. The introduction of these processes has led to greater productivity and manufacturing efficiency and lower manufacturing costs. Although the submerged-arc and inert-gas processes have been successful and have been of great assistance, industry has searched for a manual-welding process capable of depositing a continuously fed electrode at a rapid rate and yet be as versatile as covered electrodes.

During the last five years, the Linde research and development laboratories have been engaged in an intensive program to develop a versatile manual-welding

process. This work culminated with the development of a magnetic-flux gas-shielded arc-welding process that produces high-quality welds in mild steel in all positions at greater welding speeds and lower welding cost than covered electrodes. This paper briefly describes the outstanding features of this new arc-welding process.

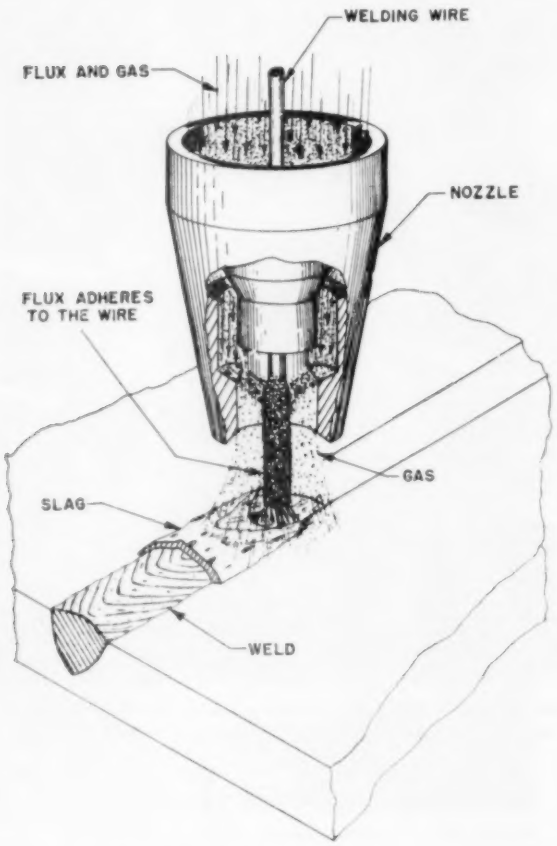

Fig. 1 The flux is attracted to the wire by the magnetic field surrounding the wire when welding current flows

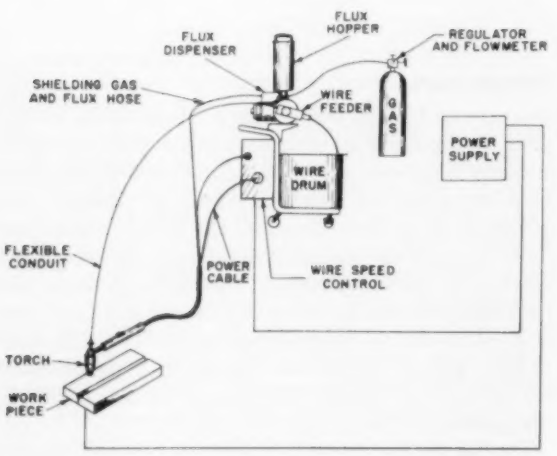

Fig. 2 Schematic representation of apparatus, equipment and accessories employed with new method

Process Description

The essential components of magnetic-flux gas-shielded arc welding, as described in this paper, are: bare-steel welding wire, magnetic flux, carbon-dioxide gas and welding current. During welding, the wire and a suspension of flux in gas are fed simultaneously to the torch. Here, the welding current flowing through the wire establishes a magnetic field that attracts the magnetizable flux to the wire (Fig. 1). As a result, the electrode or wire is "flux-coated." The flux stabilizes the arc, refines and protects the puddle and controls the weld contour and coalescence. Besides conveying the flux to the torch, the carbon dioxide provides supplementary shielding and in combination with the flux provides desirable arc characteristics. This process is shown in operation schematically by Fig. 2.

The arc characteristics of the new process are similar to those of covered electrodes. Under most welding conditions, metal transfer is "spray-type" and very

Fig. 3 Commercially-available equipment used for magnetic-flux gas-shielded arc welding

little spatter is evolved. Such spatter as is produced by this process is not tenacious and is readily removed by wiping or light brushing.

The welding techniques used with magnetic-flux gas-shielded arc welding are about the same as those employed with the most commonly used electrodes. After a few hours of practice, an operator familiar with covered-electrode welding will produce excellent welds with this new method. Manual skill and dexterity requirements are about equivalent or less than those for covered-electrode welding.

Equipment

The equipment is somewhat similar to that used with submerged-arc and inert-gas welding. The machine shown in Fig. 3 utilizes bare wire contained in drums of approximately 300 lb capacity. A thyratron-controlled shunt motor provides wire feed at a constant rate and drives the flux dispenser. In this manner, the flux flow is made proportional to wire feed. The flux to wire ratio can be adjusted by rotating the flux hopper. The wire is fed through a 16-ft long flexible conduit. The flux is fluidized by the carbon-dioxide stream and is fed through a hose to the electrode holder or torch. Although this torch resembles an inert-gas torch, it does not require water cooling. A constant-potential d-c power supply is usually used. Conventional drooping power supplies can be used for many jobs, particularly when high welding-current densities are used.

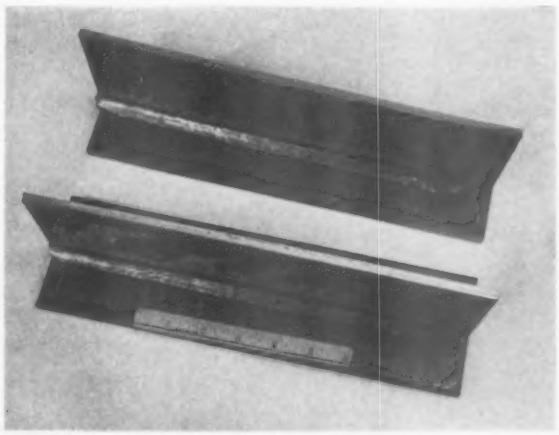

Fig. 4 Lap-fillet weld in $^{5}/_{16}$-in. mild steel

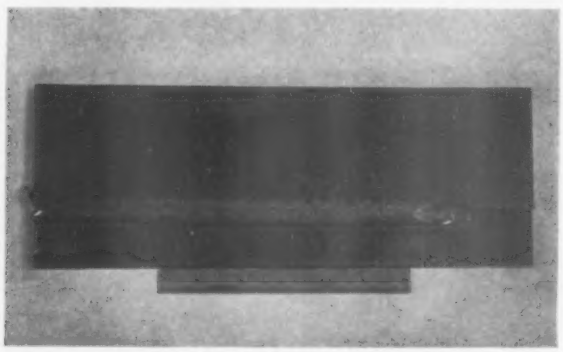

Fig. 5 Horizontal fillet welds in $^{1}/_{4}$-in. hot-rolled mild steel

Process Application

Welding Wire Section

Wire of various diameters can be used with magnetic-flux gas-shielded arc welding; however, the requirements of most welding applications can be met by the wide operating ranges of $^{3}/_{32}$- and $^{3}/_{64}$-in. diam wires. As a result, the required equipment was designed around these two wire sizes. Wire of $^{3}/_{32}$ in. diam is generally used for welding in the flat and horizontal positions. Wire of $^{3}/_{64}$ in. diam is used in all positions—flat, horizontal, vertical and overhead.

Flat and Horizontal Positions

For flat and horizontal welding, wire of $^{3}/_{32}$ in. diam is used over a current range of approximately 350 to 500 amp DCRP with a flux-to-wire ratio of 0.5 lb flux per lb of wire. Single-pass fillets of 1 in. size can be made in the flat position and single-pass fillets of $^{3}/_{8}$ in. size can be made in the horizontal position. Single-pass $^{5}/_{16}$-in. leg lap fillet welds can be easily produced as shown by Fig. 4. Larger fillet welds are easily made by multipass welding. Even at high welding currents and speeds on the order of 25 ipm, undercut-free fillet welds can be produced without difficulty, as illustrated by Fig. 5.

Butt welds in 1-in. thick material can be easily made in the flat position by applying one pass from each side. Multipass techniques are used for welding heavier materials. The weld shown on Fig. 6 was made in $^{3}/_{4}$-in. thick plate using one pass from each side. Root passes can be readily applied in joints where poor fit-up and gaps are encountered and, in many instances, the process will be ideal for providing backing passes for submerged-arc welding.

All Positions

Welds can be made in all positions with $^{3}/_{64}$-in. diam wire and flux-to-wire ratios in the range of 0.3 to 0.6. Welding currents used vary from 125 to 250 amp, DCRP, depending upon joint and position.

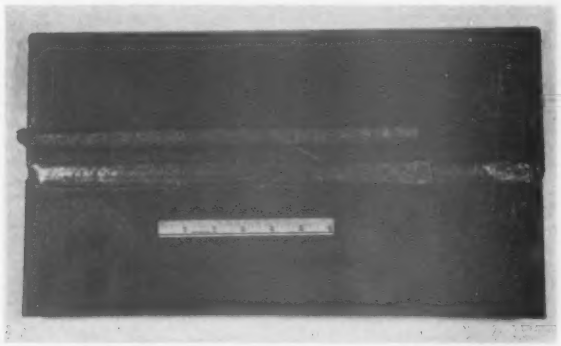

Fig. 6 Butt weld made in $^{3}/_{4}$-in. thick material using one pass from each side at 425 amp. No back-chipping is required

In all positions, lap, tee-fillet and butt welds can be readily produced in all thicknesses of materials. Multipass techniques are used on heavy plate. Figure 7 illustrates a four-pass butt weld prepared in the horizontal position. Figure 8 shows two vertical-up fillet welds made with straight-line and weaving techniques. A fillet weld made in the overhead position is shown in Fig. 9.

Weld Quality

Welds of all types were made on steels conforming to the most common ASTM classifications such as A283, A285, A7, A212 and A201. These steels were representative of carbon and deoxidation variations used for at least 75% of all mild steel fabricated. All welds exhibited excellent quality as shown by Fig 10, and easily met radiographic requirements of paragraph UW51 of Section VIII, ASME boiler and pressure vessel code. All plate was covered with either normal mill scale or rust and plate edges were prepared by oxygen cutting. Weld joints were not ground or wire brushed prior to welding. Since fillet, butt and plug welds, and casting repairs exhibited consistently excellent radiographic quality in these materials, the quality of welds produced with this new arc-welding process can be said to be reasonably independent of material. Figure 11 shows cross sections of fillet welds prepared with this process and with covered electrodes. Note the comparable weld shape but the greater penetration of the magnetic-flux gas-shielded arc weld. Slag removal is excellent as evidenced by Fig. 6.

Mechanical Properties

Multilayer welds were prepared in accordance with ASTM-AWS Specification A233–48T to determine mechanical properties. Typical results are shown on Table 1. These exceed those obtained with E6010 and E6012 electrodes. Standard side, root and face bend tests indicated that welds will exhibit completely satisfactory soundness and bending properties. Multilayer welds contained 0.09% carbon, 0.90% manganese and 0.30% silicon along with normal

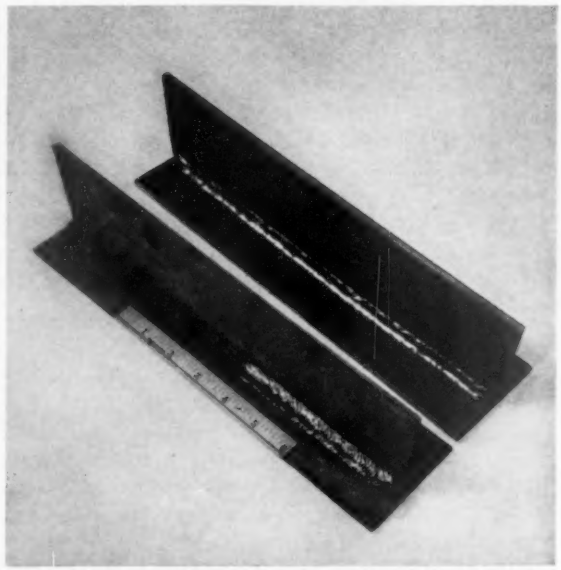

Fig. 8 Vertical-up fillet welds in $^1/_4$-in. thick mild steel. Top weld was made with a straight line motion. Weave technique was employed for bottom weld

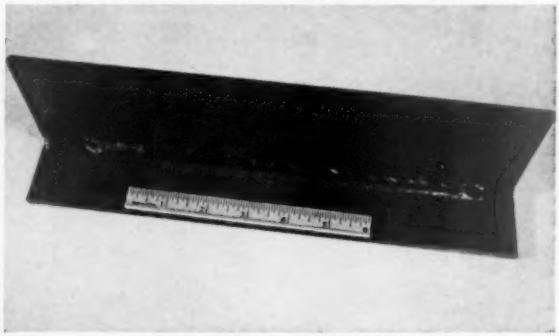

Fig. 9 Overhead fillet weld of $^1/_4$-in. size made at 11 ipm

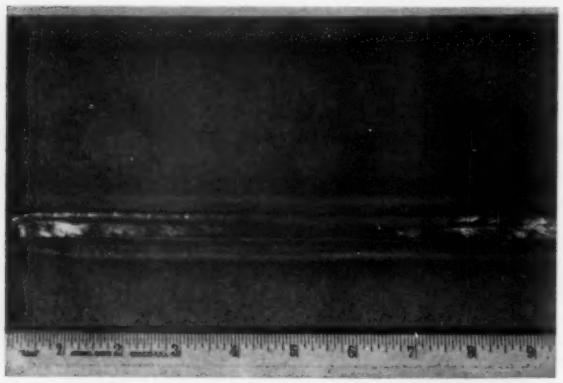

Fig. 7 Butt weld prepared in the horizontal position with two passes from each side

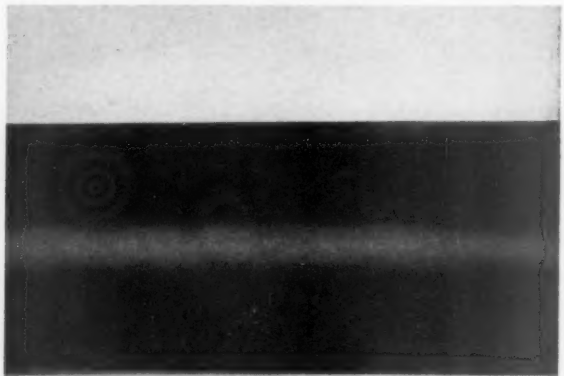

Fig. 10 Radiograph of two-pass butt weld made in $^3/_4$-in. thick A285 steel plate

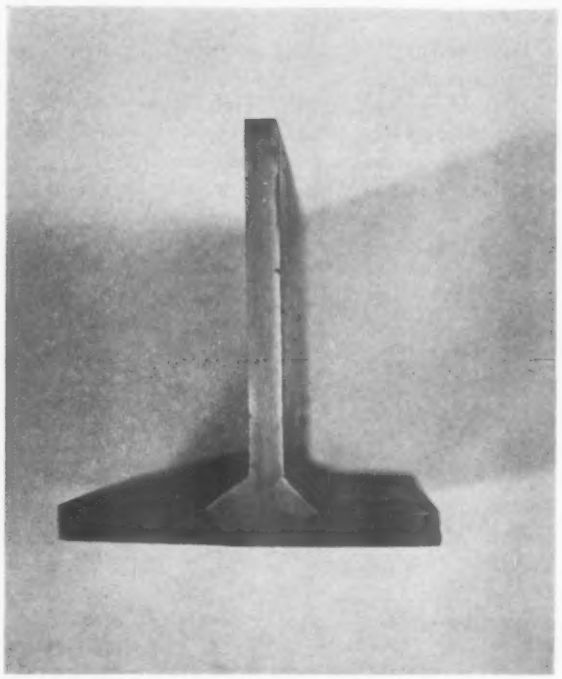

Fig. 11 Sectioned horizontal fillet welds—left, magnetic-flux gas-shielded; right, covered electrode

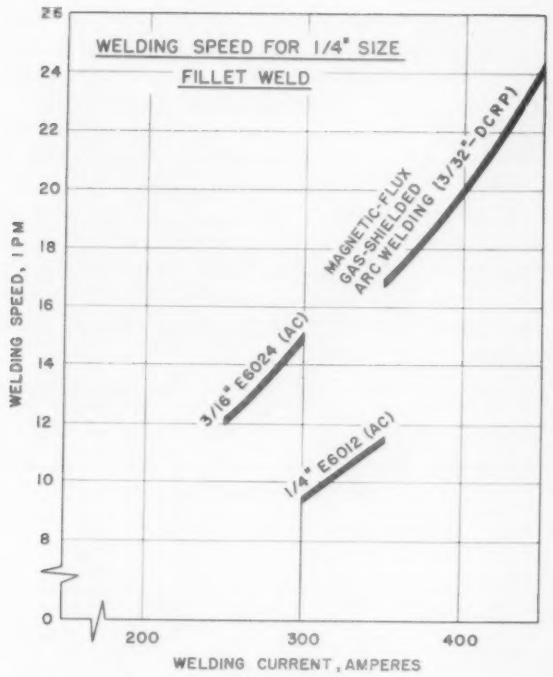

Fig. 12 Comparison of deposition rates of magnetic-flux gas-shielded arc welding using $^3/_{64}$- and $^3/_{32}$-in. diam wire with $^3/_{16}$-in. E-6024 and $^1/_4$-in. E-6012 electrodes

amounts of sulfur, phosphorus and other elements.

Comparison with Covered-Electrode Welding

As a part of the laboratory investigation, deposition data were obtained for magnetic-flux gas-shielded arc welding using both $^3/_{32}$- and $^3/_{64}$-in. wires and various types and sizes of covered electrodes. This information is summarized in Fig. 12. For simplicity, data for only two covered electrodes are shown since these electrodes are the most commonly used for downhand welding. These data are in close agreement with those shown in the literature.[1–4] It can be seen that wire of $^3/_{32}$-in. diam and an 0.5 flux-to-wire ratio deposits weld metal at about twice the rate of $^1/_4$-in. E6012 electrodes and about $1^1/_2$ the rate of E6024 electrodes. Moreover, the deposition rate of the new method is virtually equivalent to the wire feed or burn-off rate, despite the small spatter loss. The deposition rate of $^3/_{64}$-in. diam wire using an 0.4 flux-to-wire ratio is also rather high. In fact, when preparing welds in all positions, $^3/_{64}$-in. diam wire deposits weld metal at a rate two to three times greater than that of the commonly used E6010 and E6013 electrodes.

Table 1—Typical Mechanical Properties of Magnetic-Flux Gas-Shielded Arc Welds

Yield strength, 0.5% offset, psi	66,000
Ultimate tensile strength, psi	78,000
Elongation, % in 2 in.	28
Reduction of area, %	65
Charpy vee-notch 15 ft-lb transition temp., ° F	−40

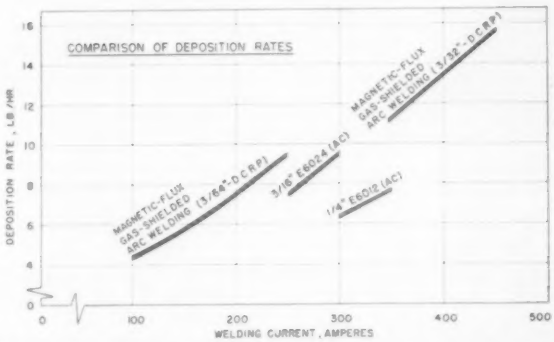

Fig. 13 Comparison of welding speeds for magnetic-flux gas-shielded arc welding and $^3/_{16}$-in. E-6024 and $^1/_4$-in. E-6012 electrodes

Since welding of fillets in the horizontal position, particularly the $^1/_4$-in. size, accounts for a large proportion of welding, a comparison was made of welding speeds and costs of magnetic-flux gas-shielded arc welding with that of the most popular electrodes for this application, $^1/_4$-in. E6012 and $^3/_{16}$-in. E6024. The results of this work are summarized in Fig. 13 and closely agree with the deposition data. Magnetic-flux gas-shielded arc welding is 50–100% faster than covered electrode welding depending upon the electrode used and current selected.

In order to determine the relative costs of each of the methods, $^1/_4$-in. horizontal fillet welds were pre-

pared at typical welding conditions as shown in Table 2. A labor rate of $2.00 per hour and overhead rate of 150% of labor rate were assumed. Since the new welding process uses a continuously-fed electrode, it was further assumed that its operating factor would be about 50% when covered electrodes had an operating factor of 40%. Cost calculations based upon data and assumptions are shown in Table 3. It can be seen that material cost represents only a small part of total welding cost. Magnetic-flux gas-shielded arc welding is much less costly than covered-electrode welding because of lower labor and overhead costs resulting from the greater welding speeds.

Table 2—Welding Data

Horizontal fillet weld—1/4 in. size

	Covered electrodes		*Magnetic-flux gas-shielded arc welding*
	E6012	*E6024*	
Rod size, in.	1/4	5/16	3/32
Welding current, amp	325 (ac)	275 (ac)	400 (DCRP)
Welding speed, ipm	10.3	13.4	20.0
Arc time, hr/100 ft	1.95	1.49	1.0
Deposited metal, lb/100 ft	13.6	13.1	13.3
Welding rod consumption, lb/100 ft	20.4	19.6	13.3
Flux consumption, lb/100 ft	...	...	6.7
Carbon dioxide consumption, cf/100 ft	...	...	35

Conclusion

Magnetic-flux gas-shielded arc welding exhibits the following advantages:

1. Welding speeds are approximately 50–100% greater than those obtained with covered electrodes.
2. Welding costs are approximately 35–75% less than those of covered-electrode welding.
3. Weld quality and appearance are excellent.
4. Penetration is excellent, uniform and readily controlled.
5. There is very little tendency toward undercutting.
6. Sizable gaps can be bridged; and weld soundness is virtually unaffected by base metal composition and surface condition.

Acknowledgments

The development of magnetic-flux gas-shielded arc welding followed the invention of the process by H. E. Kennedy of Berkeley, Calif. The authors express their appreciation for the many contributions of C. E. Jackson and G. E. Claussen formerly with the Metals Research Laboratories, Linde Air Products Co., Niagara Falls, N. Y., and now with the Development Laboratory of Linde in Newark, N. J. The authors are much indebted to F. T. Stanchus who, as a co-worker, helped to establish process applications and techniques.

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Table 3—Cost Comparison

Horizontal fillet weld—1/4 in. size

	Covered electrodes — *E6012*	*Covered electrodes* — *E6024*	*Magnetic-flux gas-shielded arc welding*
Materials cost			
Welding rod	20.4 × $0.145 = $ 2.96	19.6 × $0.19 = $ 3.72	13.3 × $0.165* = $ 2.19
Flux	..	..	6.7 × 0.35 = 2.34
Gas	..	..	35 × 0.015 = 0.05
Subtotal	$ 2.96	$ 3.72	$ 4.58
Labor and overhead cost			
Labor at $2.00/hr	$\frac{1.95}{0.4}$ × $2.00 = $ 9.73	$\frac{1.49}{0.4}$ × $2.00 = $ 7.45	$\frac{1.00}{0.5}$ × $2.00 = $ 4.00
Overhead at 150% of labor cost	1.5 × $9.73 = $14.60	1.5 × $7.45 = $11.18	1.5 × $4.00 = $ 6.00
Subtotal	$24.33	$18.63	$10.00
Total	$27.29	$22.35	$14.65

* Includes license fee.

Depositing weld on large casting

ASPECTS OF CRACK SENSITIVITY IN MACHINABLE DEPOSITS ON CAST IRON

BY R. D. WASSERMAN, J. F. QUAAS AND J. P. BRODERICK

Authors' investigation shows that nickel-iron-alloy weld deposits on cast iron are less crack sensitive than the nickel and nickel-copper types, irrespective of the grade of casting used

R. D. Wasserman, J. F. Quaas and **J. P. Broderick** are associated with Eutectic Welding Alloys Corp., Flushing, N. Y.

Presented at the 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8–12.

ABSTRACTS. Production, maintenance and repair welding of gray cast iron has been practiced for decades. The technique of welding has been considered an art due to the inherent poor physical properties of cast iron. The authors discuss the many variables which are presented in welding not only the gray cast irons but the new nodular types as well.

The use of a cast test block, so designed that stresses cannot be dissipated, provided a positive testing medium for determining the crack resistivity of nickel-base weld metal.

Coating formulations normally used by covered electrode manufacturers are mentioned. Various nickel-iron weld metal ratios were explored utilizing 60/40 standard filler alloy as electrode core material. Iron and/or nickel mesh powder was added to the basic formulations in order to deposit the various alloy balances discussed.

Table 1—Materials, Chemical Analysis*

Base metals

	Chemical range, %						
	T. C.	*Si*	*Mn*	*P*	*Ni*	*Mg*	*Others*
Gray iron, No. 4 base, ASTM A48–48, Class 20	3.25–3.50	2.75–3.00	0.60–0.75	0.50–0.72	..	..	0.08 total[1]
Nodular iron, 60-45-10, ASTM A339–51T	3.40–4.0	2.0 –2.75	0.20–0.60	0.06–0.08	0–1.0	0.02–0.07	...

Weld metals

		Weld deposit analysis, %								
Electrode No.	*Flux, %*	*T. C.*	*Mn*	*P*	*S*	*Si*	*Ni*	*Cr*	*Fe*	*Others*
56–22	37.0	1.59	0.65	0.008	0.005	0.35	52.35	0.10	45.34	...
56–24	46.5	2.05	0.55	0.006	0.007	0.47	58.74	0.15	38.52	...
56–26	43.5	1.55	0.74	0.011	0.008	0.72	53.72	0.05	43.65	...
56–27	39.2	1.90	0.51	0.010	0.004	0.91	48.05	0.10	47.95	...
56–28	36.5	1.65	0.61	0.012	0.008	0.62	45.56	0.13	49.74	...
56–30	40.5	2.01	0.52	0.007	0.007	0.82	43.50	0.15	52.80	...
56–242	20.0	0.81	0.55	0.025	0.010	0.84	95.60	0.35	Bal.	...
56–243	19.5	0.65	0.57	0.031	0.009	0.56	58.72	0.32	03.85	Cu 35.45

* Blocks were sand cast within the specification chemical values as listed. Deposited-weld-metal chemistry was determined from undiluted, machined shavings. Electrodes 56-22 through 56-30 represent binary alloy varieties commonly referred to as the nickel-iron type. Electrode 56-242 is the so-called "pure" nickel grade, while 56-243 is a modification of the standard Monel chemistry.

Results of hardness surveys are reported in pictorial chart form. The hardness investigations were made both vertically and horizontally on cross-sectional areas removed from the numerous cast test blocks.

While tests indicate that the 60/40 alloy has the greatest crack resistivity, the use of nickel and nickel-copper materials is also justified for many applications.

Introduction

Cast iron has been known for centuries as a material with special characteristics which enhanced its use for many varied applications. The brittleness of cast iron, however, has had a tendency to limit its use since the alloy's ductility is almost nil. With the advent of new ductile irons having vastly improved strength and ductility properties, the welding of gray and new grades of iron has become an important factor which must be resolved.

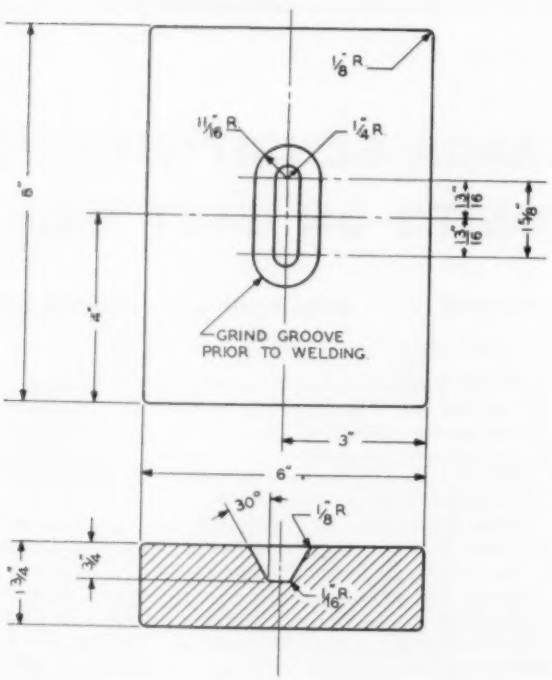


Fig. 1 Dimensions of test block

Electrode manufacturers have advocated for many years the use of a Grade A nickel core wire as the filler material to be employed when welding various cast-iron base alloys. The Grade A core material contains a minimum of 95% nickel around which is extruded a graphitic lime-base coating. The Grade A core material, however, has proved unsatisfactory on many applications. Other alloys have been explored in an attempt to find a suitable filler material for welding "difficult" cast irons. Among the many materials investigated were nickel-copper and nickel-iron alloys. The nickel-copper materials were found to be susceptible to cracking in the weld metal particularly under conditions where the joint was highly stressed. The nickel-iron materials seemed to possess excellent crack resistivity when used under adverse conditions. The coefficient of expansion of the nickel-iron alloy more closely matched that of the base cast iron upon which the deposited metal was applied. Under the circumstances, the stress condition caused by the heat effect of the welding process was equalized to some degree. The nickel-iron alloy thus proved itself compatible with cast irons when used for repair welding and fabrication.

In evaluating a new alloy to be used as core wire in a covered electrode, a test or testing method was sought which would enable the development personnel to readily interpret specific test results. Such a test would immediately show a given alloy system's resistance to crack susceptibility. Many joint types were explored including circular patch designs as well as heavily reinforced single-vee plate configurations. Test results, however, were most difficult to reproduce or verify when using such testing structures and designs. Our interest eventually was focused upon a cast test block used by Schumbacker and Schaeffler and described in a paper presented at the 1955 AWS

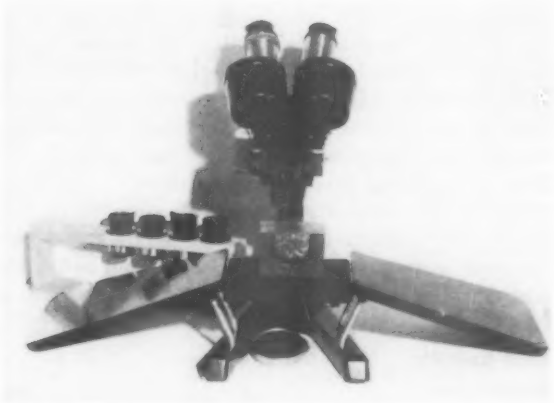


Fig. 2 Reichert steroscopic microscope

Fig. 3 Zwick microhardness tester

National Fall Meeting held in Philadelphia. The authors of said paper permitted our use of the test block as illustrated in Fig. 1. Tests employing 95% nickel, nickel-iron and nickel-copper alloy compositions as covered-electrode core materials indicated that the test block imparted severe stress concentrations to the weld metal. This condition resulted in cracking tendencies in the weld metal and/or base material. Tests indicated that this test block would cause crack propagation in all cases except where weld metal was of the highest quality and proper techniques were employed.

Materials

The chemistry of the base irons and the undiluted weld metal of each electrode used in this investigation is shown in Table 1.

Covering Materials

The coating formulations employed on the various core materials explored in this investigation are comparable to those normally used for covered electrodes of the nickel base category advocated for welding cast irons.

The flux ingredients are composed of alkaline earth carbonates and fluorides, graphite, ferro-alloy additions plus water-soluble silicates as the binder. A small percentage of clay, bentonite, talc and/or mica is incorporated within the coating formulation as an aid in the extrusion process. The fluorides provide fluxing and cleansing action on the deposited metal as well as contributing to the formation of the slag cover. The carbonates are considered an integral part of the coating formulation not only from a slag forming point of view but also from an arc-stabilizing aspect. The decomposition of the carbonates at arcing temperatures provides a gaseous shield which protects the weld metal from oxidation. The graphite constituent contributes to the stability of the arc and is very effective in lowering the amperage required for proper deposition. The graphite has a secondary effect in minimizing slag volume due to its reducing characteristics.

The nickel-iron series explored were manufactured using the nominal 60/40 grade of core wire. The range of nickel and iron contents as shown in Table 1 was obtained by additions of nickel and/or iron mesh powder to the various formulations.

Test Procedure

All sample castings were tested in the as-welded condition. Cross sections were mechanically removed from the weldment and examined for defects after polishing. A binocular, stereoscopic microscope (Fig. 2) was found to be extremely helpful for crack detection and analysis. Various lighting techniques were devised to accentuate the three-dimensional effect in an attempt to determine crack origin and propagation.

For measuring comparative hardness values, a 136-deg diamond pyramid hardness tester of European manufacture was selected (Fig. 3). Based on the Vickers principle, the apparatus proved especially suitable in making this survey. A dead-weight load of 2 kg was found to produce indentations which were readily evaluated. The manually operated trip mechanism independently adjusts the rate of load and is not subject to variation due to hydraulic malfunctioning. The 136-deg diamond shape appeared to be advantageous when tracking the weld-base metal interfaces particularly in the nodular blocks. The indentation can be more readily located so as to prevent interference by the individual nodules when determining diagonal measurements. Hardness values were then calculated from available tables and plotted on the charts, as shown in Figs. 4 through 11.

Welding Procedure

The casting skin was removed from the weld area by grinding and deburring with powered hand tools. The blocks were then preheated in an electric oven, held at 500° F for 1 hr and placed within a refractory-brick enclosure on the test bench. All welding

was accomplished in the downhand position using $^{5}/_{16}$-in. electrodes and direct current supplied by a motor generator. Electrodes of the binary, nickel-iron type were deposited using reversed polarity, whereas straight polarity was selected for the nickel and nickel-copper grades. Machine settings were within those ranges generally prescribed for electrodes of this size and type. Actual arcing amperages and voltages were continually plotted on standard recording meters.

In establishing the arc, care was exercised in minimizing initial thermal shock by using a low-electrode-contact angle. After sufficient weld-metal pile-up, forward travel commenced, completing the root pass. The weaving technique was used and the rate of travel adjusted to prevent excessive bead convexity. The arc was directed at all times upon deposited weld metal and extinguished over the crater after proper build-up. Conventional slag-cleaning methods were employed, using hand-operated chipping and brushing tools. An interpass temperature equal to the degree of preheat (500° F) was constantly checked with small, contact-type pyrometers. Refractory covering of the block between passes appeared to aid heat distribution within the casting. The peening technique was not employed. Prior to applying each successive deposit, the direction of travel was reversed to aid in maintaining uniformity of height and heat dissipation Typical pass sequence is shown in Fig. 12. Upon completion, the casting was allowed to return to room temperature in still air.

Test Results

Nodular Iron

This investigation revealed that when welding nodular irons the crack resistivity of the nickel-iron alloy electrodes was superior to the nickel and nickel-copper types. This was found to be true irrespective of nickel

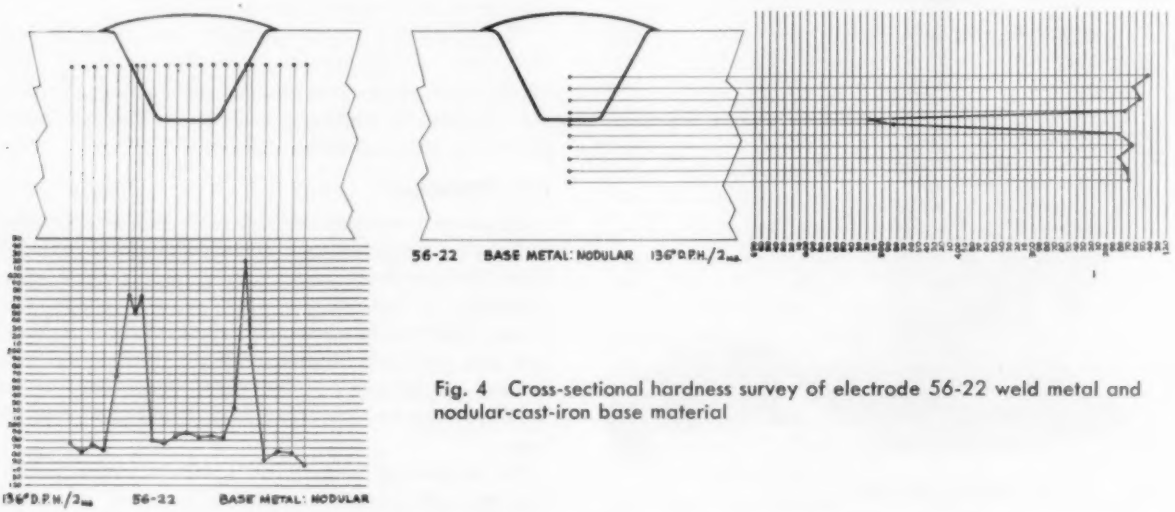


Fig. 4 Cross-sectional hardness survey of electrode 56-22 weld metal and nodular-cast-iron base material

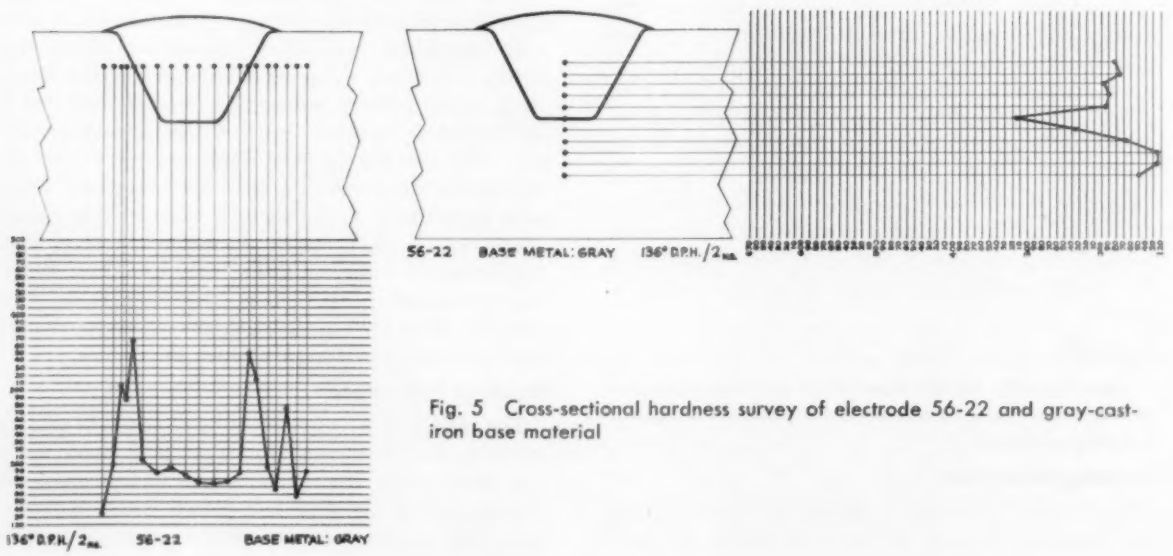


Fig. 5 Cross-sectional hardness survey of electrode 56-22 and gray-cast-iron base material

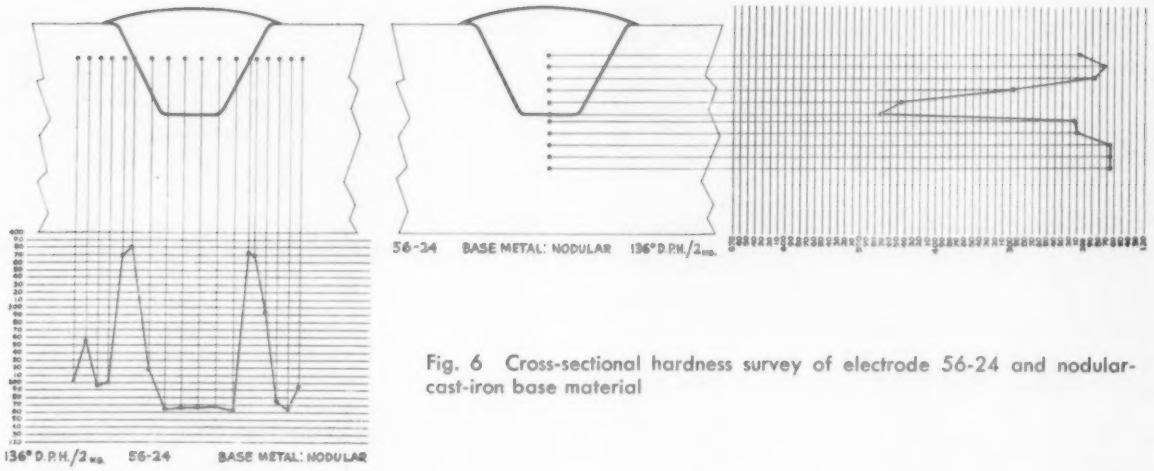


Fig. 6 Cross-sectional hardness survey of electrode 56-24 and nodular-cast-iron base material

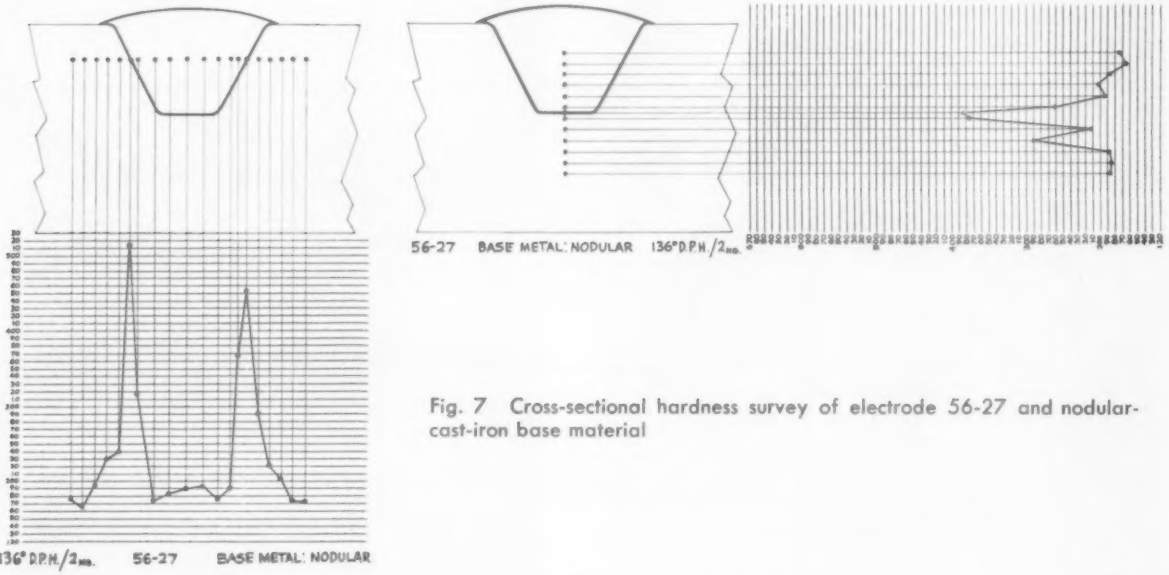


Fig. 7 Cross-sectional hardness survey of electrode 56-27 and nodular-cast-iron base material

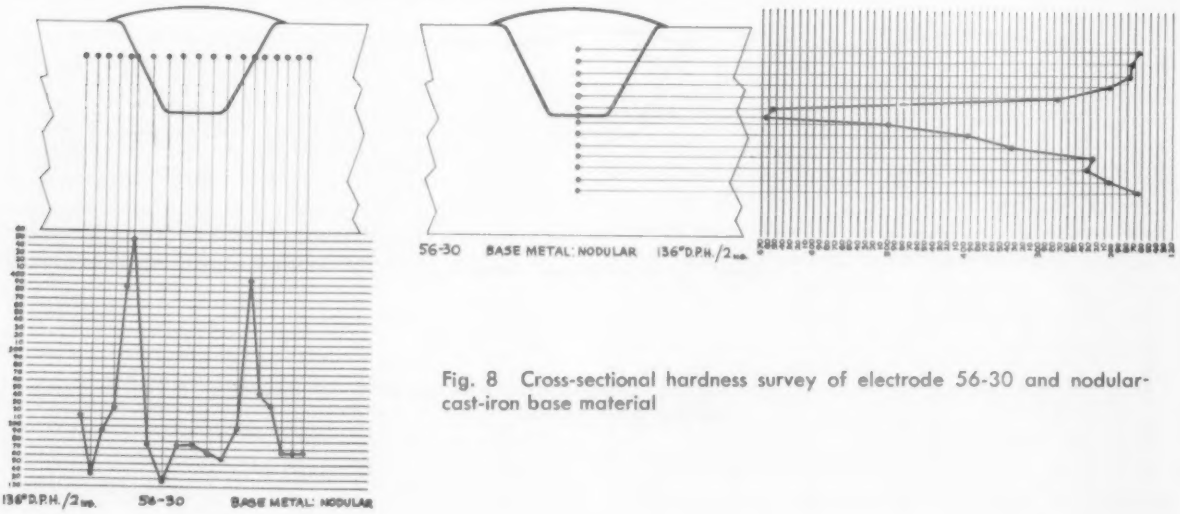


Fig. 8 Cross-sectional hardness survey of electrode 56-30 and nodular-cast-iron base material

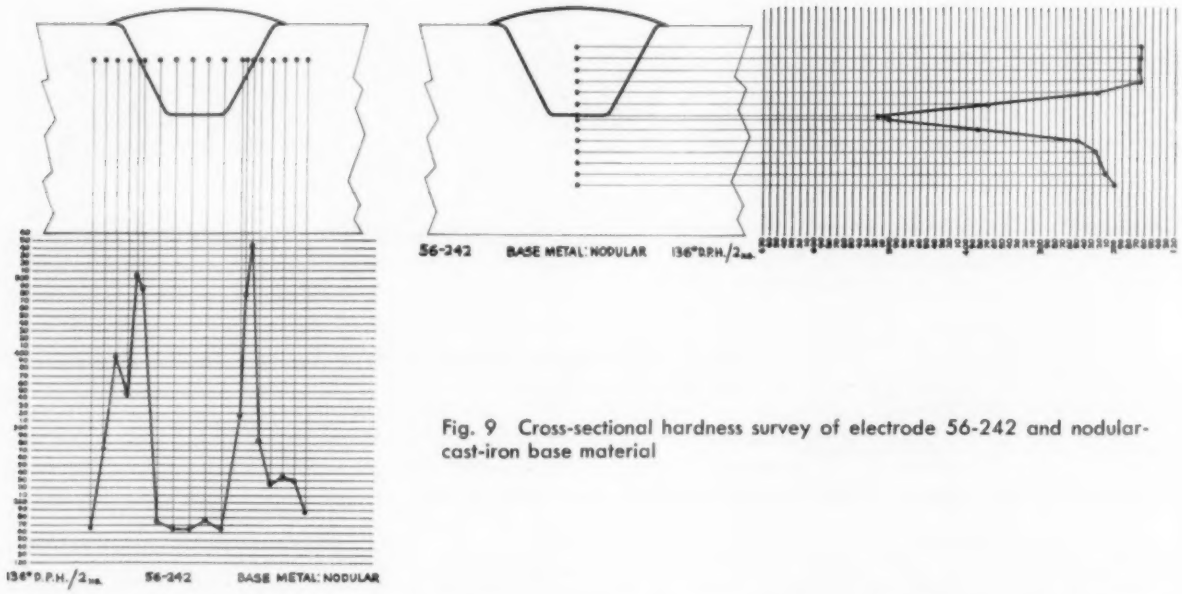


Fig. 9 Cross-sectional hardness survey of electrode 56-242 and nodular-cast-iron base material

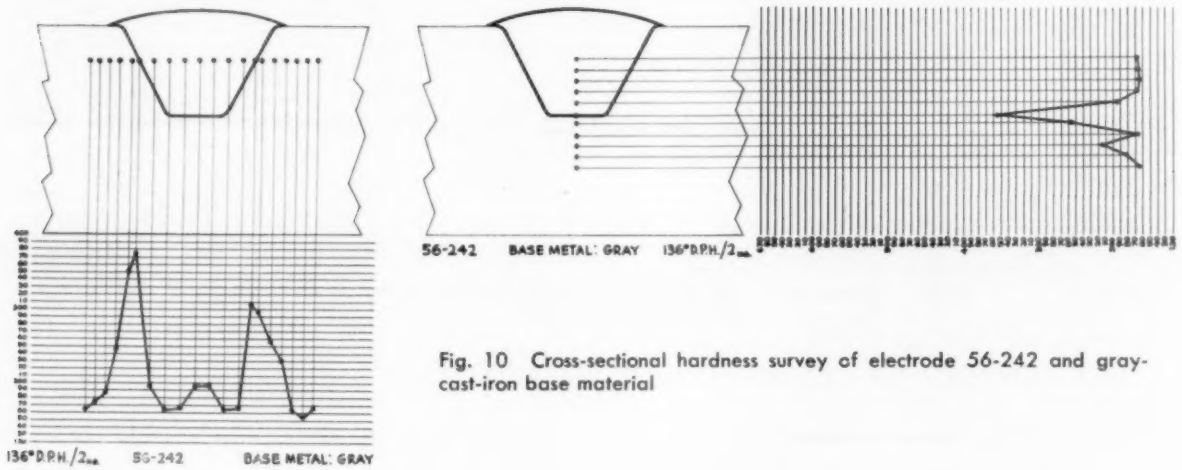


Fig. 10 Cross-sectional hardness survey of electrode 56-242 and gray-cast-iron base material

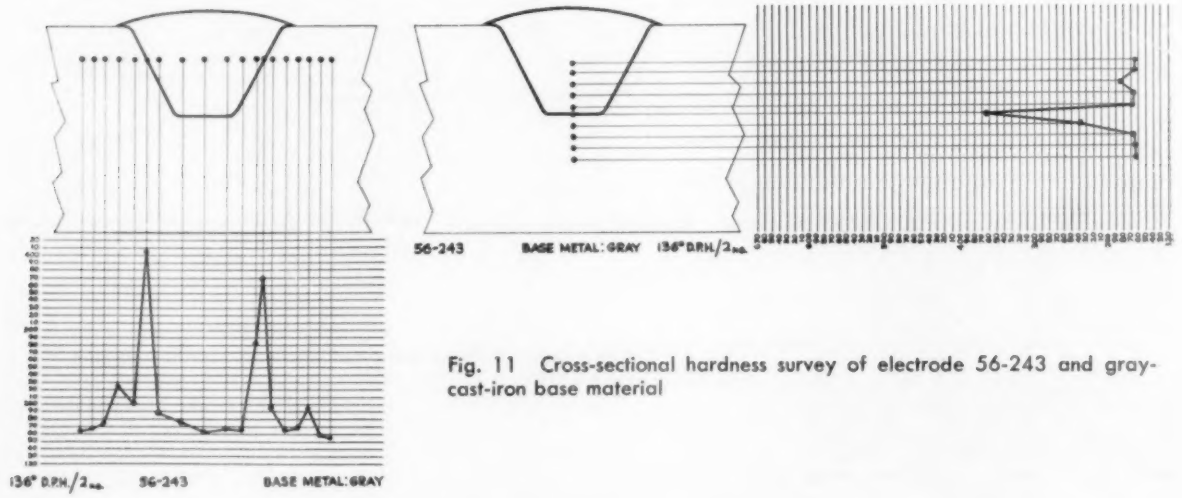


Fig. 11 Cross-sectional hardness survey of electrode 56-243 and gray-cast-iron base material

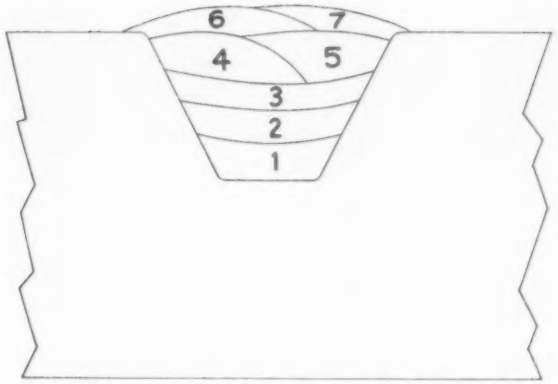


Fig. 12 Welding technique employed—pass sequence

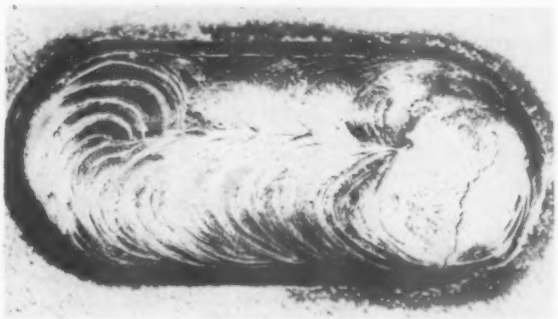


Fig. 13 Photomacrograph of typical weld-metal cracks obtained in fifth pass of a test weldment. X 2

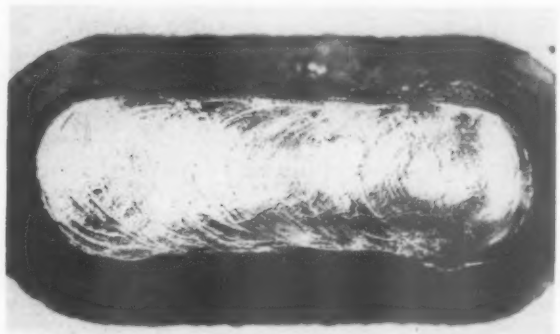


Fig. 14 Photomacrograph of typical weld-metal cracks obtained in first pass of a test weldment. X 2

iron alloy balance. Where these alloys did exhibit cracking in the test block, a preheat and interpass temperature of 500° F eliminated this condition. Crack-resistant weld metal using nickel and nickel-copper alloys as core-wire materials was difficult to obtain even at higher preheat levels.

Gray Iron

When using test blocks of the gray iron category at ambient and with 500° F preheats, the nickel and nickel-copper alloys produced cracking in the test block. Electrode 56–22 was the only electrode of the nickel-iron series explored on gray iron. Using no preheat and a continuous welding procedure, a small crater crack was observed in the third pass. With a preheat

Fig. 15 Typical macrographic view of cross-sectional area of test-block weldment. Etched with ammonium persulphate. Actual size

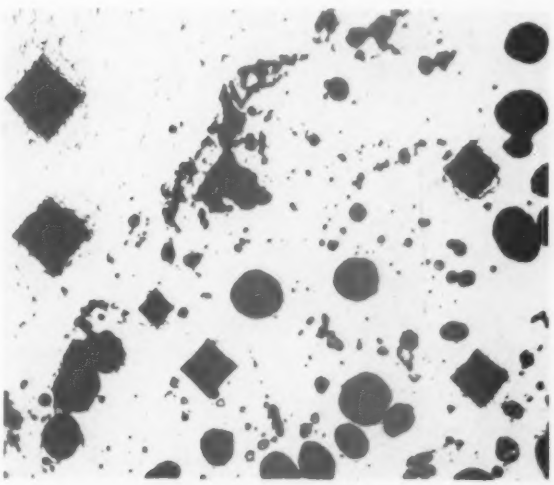


Fig. 16 Microphotograph of heat-affected zone of a welded test block depicting hardness indentations made in hardness surveys. Etched with acetic and nitric acids. X 100. (Reduced by $^1/_4$ upon reproduction)

and interpass temperature of 500° F, a crack-free deposit was obtained.

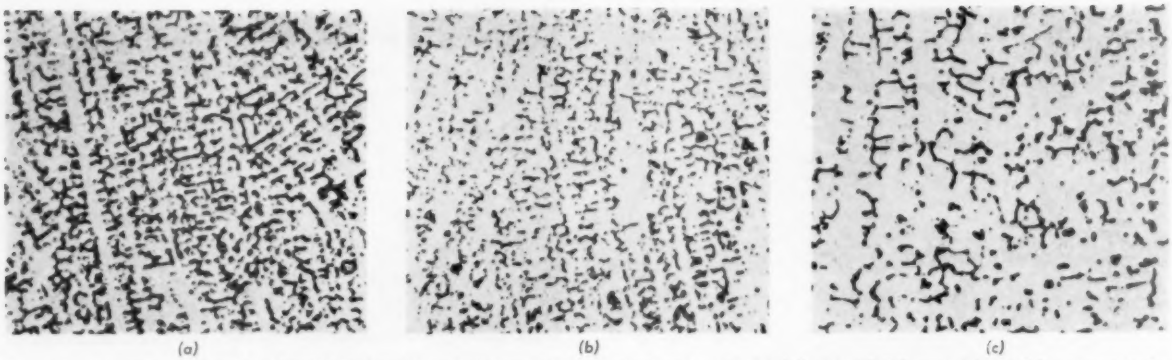
Metallography

Photomacrographs in Figs. 13 and 14 depict examples of cracking as visually observed. The dark area is the vertical walls of the concavity in the test block.

Macrophotograph in Fig. 15 shows a typical section of the welded test block. Figure 16 is indicative of the shape of the hardness indentations made by the 136-deg diamond penetrator. Photomicrographs in Fig. 17 (*a*, *b* and *c*) are structures of undiluted weld metal of electrodes 56-22, 56-27 and 56-30, respectively. The carbide phase indicated by the darkly etched constituent was observed and depicts the effect of chemistry in the nickel-iron electrode series. Figure 18 (*a* and *b*) shows the structures of undiluted weld metal as deposited by electrodes 56–242 and 56–243.

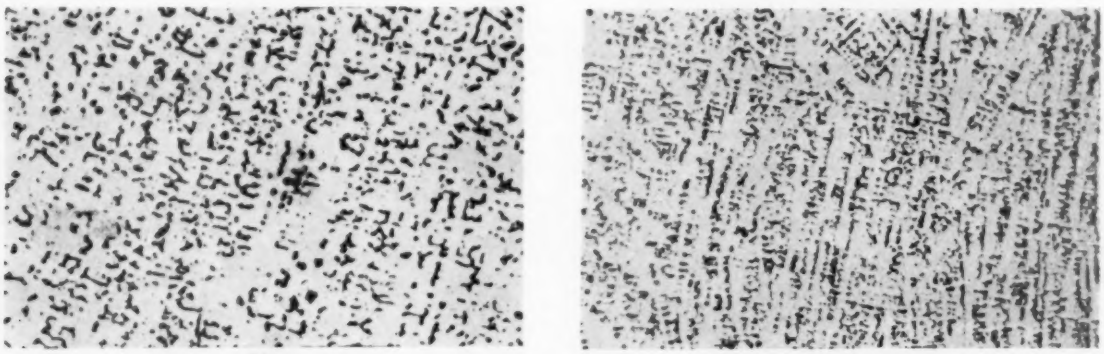
Summary and Conclusion

The test block used in this investigation showed that



(a) (b) (c)

Fig. 17 Microphotographs of undiluted weld metal deposits with electrodes 56-22 (a), 56-27 (b) and 56-30 (c), respectively. Etched with acetic and nitric acids. X 100



(a) (b)

Fig. 18 Microphotographs of undiluted weld metal deposited with electrodes 56-242 (a) and 56-243 (b), respectively. Etched with acetic and nitric acids (56-242) and ferric chloride (56-243). X 100

electrodes depositing nickel-iron alloys appear to be less crack sensitive than those of the nickel and nickel-copper types irrespective of base casting grade. Complete freedom from cracking can be realized with the nickel-iron alloy providing proper temperature control is maintained. Preheat and interpass temperatures in the order of 500° F appear to be sufficient.

Nodular iron, due to its inherently superior ductility, is considered less sensitive to weld-metal variables and technique than standard gray irons.

Since alloys covered in this investigation are considered machinable, hardness readings were plotted both vertically and horizontally on cross sections removed from the welded test blocks. Results of these surveys have been presented in pictorial-graph form to permit immediate interpretation. The hardness charts often reveal high hardness values in the interface zone but such readings will vary depending upon the exact structure penetrated by the diamond.

The test block is considered of torturous design from a crack-susceptibility viewpoint and was of utmost importance in this exploration. Locked-in stresses are provided no means of escape or dissipation due to the geometry of the groove. It is unlikely that such conditions would be present in the greater majority of field applications wherein castings are repaired by welding. Joint preparation generally includes some provision to aid in relieving stresses. Skip-welding techniques are employed and restrictions placed on the length of individual deposits in an attempt to prevent localized overheating. Often, various peening procedures might prove a deciding factor in borderline cases. End uses for castings so repaired seldom involve extensive shock loading in operation. Only those joints requiring liquid tightness are critical as regards the degree of internal fissuring permitted.

Repairs which require subsequent machining are more cautiously handled. Retarded cooling from welding temperatures tends to minimize the depth of hardening at the interface. Postheat treatment in the form of a graphitizing anneal can also be employed to improve machinability.

While test results imply that nickel-iron materials are more crack resistant, the use of nickel and nickel-copper alloys is nevertheless justified. It is suggested that individual applications be carefully explored before a specific filler metal is selected. The size and shape of the casting should be considered as well as position of welding, joint preparation, operator skill and end use.

Acknowledgments

The authors wish to express their appreciation to their Technician, John McCall, for the metallographic work performed in the preparation of this paper.

References

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PRESSURE WELDS REACH 500,000 MARK

155-lb rail welded on Pennsylvania Railroad

Pennsylvania Railroad's Conway Yard was recently the site of a record-setting operation—completion of the 500,000th oxyacetylene pressure weld on 155-lb main line rail (see Figs. 1, 2 and 3). This event marks a milestone in the use of welded rail.

Based on a story by the Linde Air Products Co., New York, N. Y.

Pressure welds have reached the half-million figure

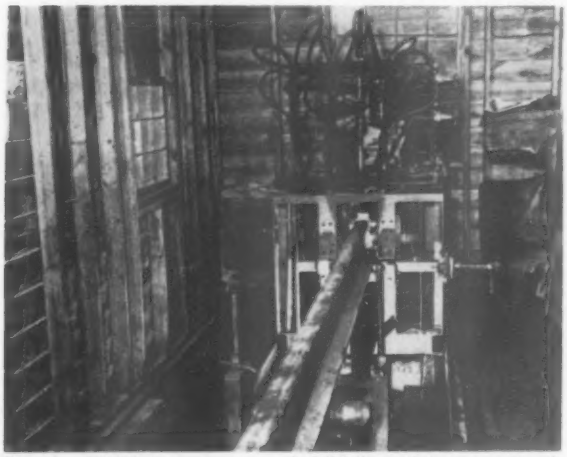

Fig. 1 Weld in a section of 155-lb rail is normalized. After it cools, upset will be ground from weld area

Fig. 2 Close-up of pressure welding operation. New and improved welding techniques have reduced the cost of welds until they are competitive with bolted joints

Fig. 3 Milestone emerging from the production line. Welded, normalized and ground, the 500,000 welded joint is ready for service

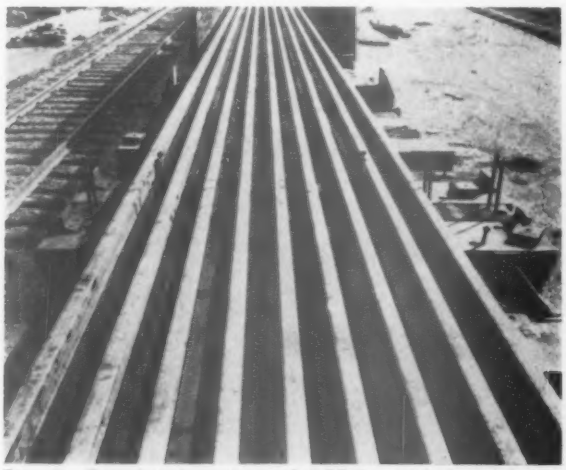

Fig. 4 Completed sections of 155-lb welded rail being loaded upon flat cars at Pennsylvania Railroad's Conway Yard

Fig. 5 Welded rail flexes as flat cars pass through an "S" curve on route to installation point

after approximately 18 yr of growing use and acceptance. A sizable portion of this total was accounted for in the past two years, during which period almost every major railroad, and many smaller roads, initiated rail-welding programs. It is estimated that in 1956 alone, rail for yards, bridges, stations and main lines totaled more than 180,000 welds. Prospects for 1957 are well beyond the 250,000 mark.

Reduced track maintenance costs are anticipated with pressure-welded rail. Today, improved pressure-welding techniques have reduced welding costs to where the welded joints are competitive with bolted joints.

The 155-lb rail welded at the Conway Yard is being transported on flat cars in regular trains to a point near Charlestown, Md. where it will be positioned in the main line (see Figs. 4 and 5).

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BACK-TO-BACK SETUP FOR SEMIAUTOMATIC WELDING OF TRAILER FRAME BEAMS

BY ALBERT T. BAVARIA

In fabricating the heavy box-section frame beams for a 15-cu yd, 20-ton capacity semitrailer used in quarrying operations, the Easton Car & Construction Co., Easton, Pa., worked out an interesting setup for semiautomatic, submerged-arc welding of 20-ft side members, two at a time.

As shown in Figs. 1 and 2, the beams comprise channel sections of 9-in. ship channel, 23.9 lb (9 x $3^1/_2$ in.). Two channels are clamped securely by bolting bars, back-to-back, and then are placed on a work table at bench height where the outer top flange is further clamped and wedged. An $8^1/_2$-in. wide plate to complete the box section is fitted between the exposed flanges and tack welded at 18-in. intervals with 1-in. tacks. The same procedure is followed on the reverse side.

Mounted on a steel platform running the length of the beams and flush with the inserted plate member is a converted self-propelled gas cutting buggy, carrying a flux cone and electrode wire feed nozzle. Operating at about 450 amp dc and with $^5/_{64}$-in. mild-steel wire fed continuously into the arc, the welding head travels squarely along the joint at a speed of around 30 ipm.

The operator merely observes the travel, meanwhile removing excess flux by means of a vacuum hose and brushing off slag accumulated on the weld bead. The buggy is guided by means of two wheels riding along the outer edge of the supporting platform, and is propelled by a larger driven wheel tracking about 6 in. inside the joint.

When one joint has been run, the beam assembly is turned over for a similar operation on the other near side; then is reversed again for the second joint on the first side, and finally again for the fourth and concluding run. By this sequencing of welds and by clamping the channel faces tightly, any stresses in the weld are, to a degree, counterbalanced and possible warpage minimized.

Straightness must be held within close limits to meet subsequent assembly demands, when the frame side members are fitted with cross bracing and other elements. Distortion is, of course, further kept at a minimum by virtue of the high welding current and fast travel speed. Penetration on the order of 50–70% is realized, ample for strength and rigidity requirements of the trailer frame.

Albert T. Bavaria is Welding Engineer, the Lincoln Electric Co., Bethlehem, Pa.

Fig. 1 Setup of two 20-ft frame members for a 20-ton semitrailer, comprising back-to-back, $^5/_8$-in. channels, with plate of similar thickness being automatically welded between the flanges

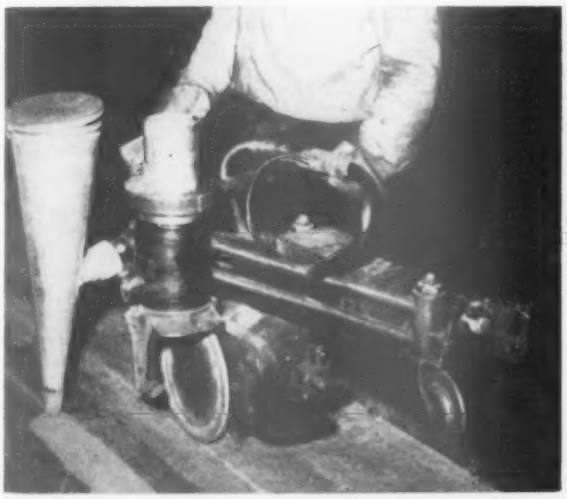


Fig. 2 Close-up of the welding "gun," mounted on a converted self-propelled gas-cutting buggy which guides the electrode point and enveloping flux squarely along the butt joint

MACHINE SHAVES WORK MINUTES TO SECONDS

A unique machine combines the use of both hydraulic and electrical systems to form and weld stator core wrappers for fractional hp electric motors in 36 sec.

Designed and built by Standard-Modern Tool Co. Ltd., Toronto, Canada, the machine uses mechanized inert-gas metal-arc welding to reduce this formerly time-consuming process from a matter of minutes to seconds. Previously, the wrappers were preformed in a hand operated rolling machine, then clamped and manually welded in approximately double the time necessary for mechanized welding.

Advantages of the argon-shielded consumable electrode metal-arc method make this electric welding process particularly suitable for this job. It enables the company to maintain reasonable tolerance in material thickness and joint fit-up, has high welding speeds, and produces uniform welds which need no cleaning.

In production, a stator, complete with windings, insulation and connection lugs, is placed in position on a mandrel before the machine operation. Then, a wrapper sheet, preformed by a special shearing-forming die in a conventional press, is positioned at a stop on the forming jaws.

After a start button is pushed, the bottom die rises against the underside of the wrapper. By means of a rack and pinion, the upward movement of the lower jaw swings the two side jaws approximately halfway to

Based on a story by the Linde Air Products Co., New York, N. Y.

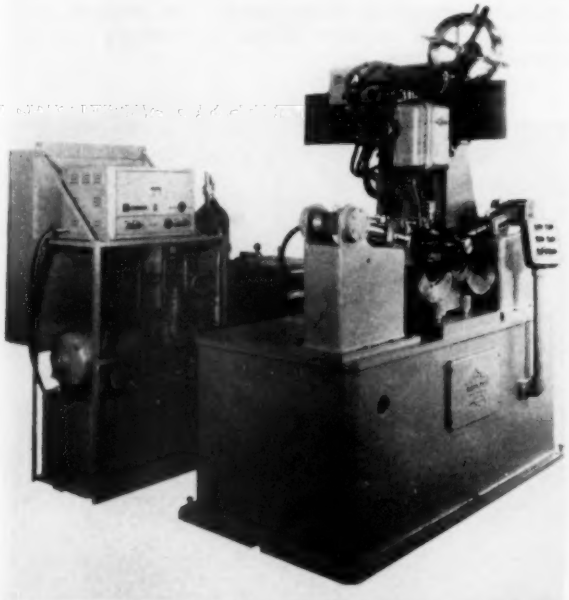


Fig. 1 Work area of this mechanized installation is shown at the right. Welding power rectifier, hydraulic system, main control cabinet and welding head control are located at the left

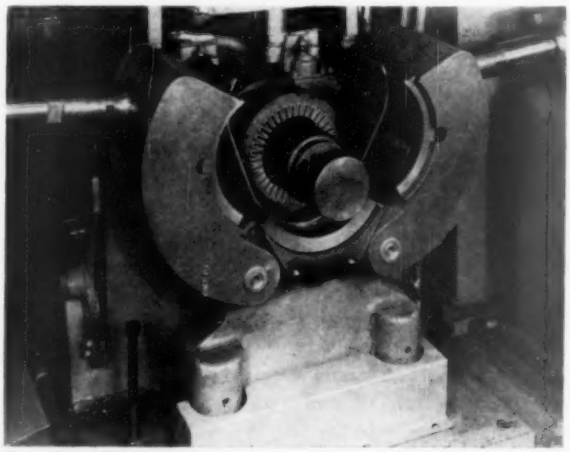


Fig. 2 After the bottom die rises against the wrapper sheet, side jaws are moved upward for alignment with side rams by means of a rack and pinion. Hydraulically-powered rams push jaws together to form wrapper for the stator core

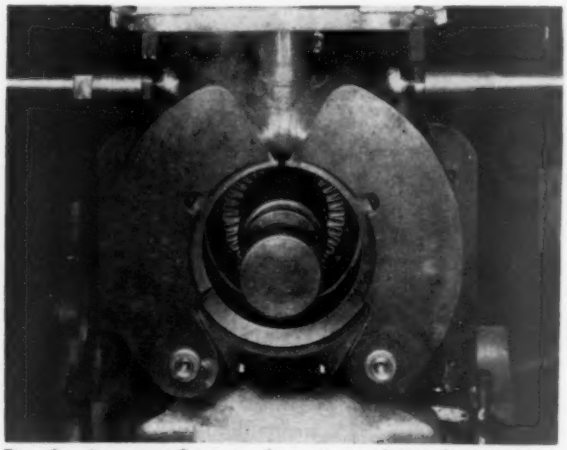


Fig. 3 Average floor to floor time of this forming and welding operation is 36 sec. When the weld is completed, the welding head returns to starting position and shuts off automatically

their final position, aligning two hardened socket-type inserts in the jaws with side rams. Hydraulic cylinders operate the rams, forcing the jaws together, as illustrated in Fig. 2.

When the jaws have closed, the welding outfit starts automatically and continues welding to the end of the seam. Upon completion of the single-pass weld, the welding head returns to the starting position and shuts off automatically (Fig. 3). Simultaneously, all three jaws drop away. The completed assembly is then hydraulically ejected from the mandrel. (A hydraulically-powered ejector was built into the machine shown in Fig. 1, after this photograph was taken.)

A $^{1}/_{32}$-in. gap between the ends of the wrapper is needed to obtain a well-penetrated, smooth weld without undue reinforcement. The weld starts and finishes a short distance from the edges of the wrapper because the assembly is machined to receive end plates in a later operation, after which no unwelded sections remain.

ALUMINUM GAS-CARRYING PIPE LINE INSTALLED IN TEXAS RURAL AREA

Installation of a major aluminum, gas-carrying pipe line that resists corrosion without costly external protection was recently completed.

Eight inches in diameter and 20,000 ft in length, the big pipe line ranks as the largest, longest unprotected aluminum gas transmission line now in service. It was installed by Lavaca Pipe Line Co. as part of the gas transportation system servicing Aluminum Company of America's Point Comfort (Tex.) operations.

Extending through nearly four miles of rural area, the schedule 40 pipe is buried in soil ranging from sand and gumbo, to salty marsh (see Fig. 1). Completely devoid of protective coatings and anodes, the aluminum line is shielded only by electrical insulation at certain flanged joints. Anodes will be installed on test sections, however, to provide a detailed study of their effectiveness.

Normal procedure for steel pipe, buried under similar conditions, calls for a protective coating and complete swathing in wrapping material to guard against corrosion. Leading authorities also advise the use of cathodic protection as an additional barrier against external corrosion of steel pipe.

Elimination of these costly protective measures is expected to boost the already growing demand for aluminum in the petroleum industry.

In installing the aluminum line, 40-ft lengths were joined using the argon-shielded tungsten-arc and consumable-electrode welding methods (see Fig. 2). Gas flows through the new aluminum line at a pressure just under 500 psi. The line has been tested at 800 psi, and has a calculated bursting pressure of 1500 psi

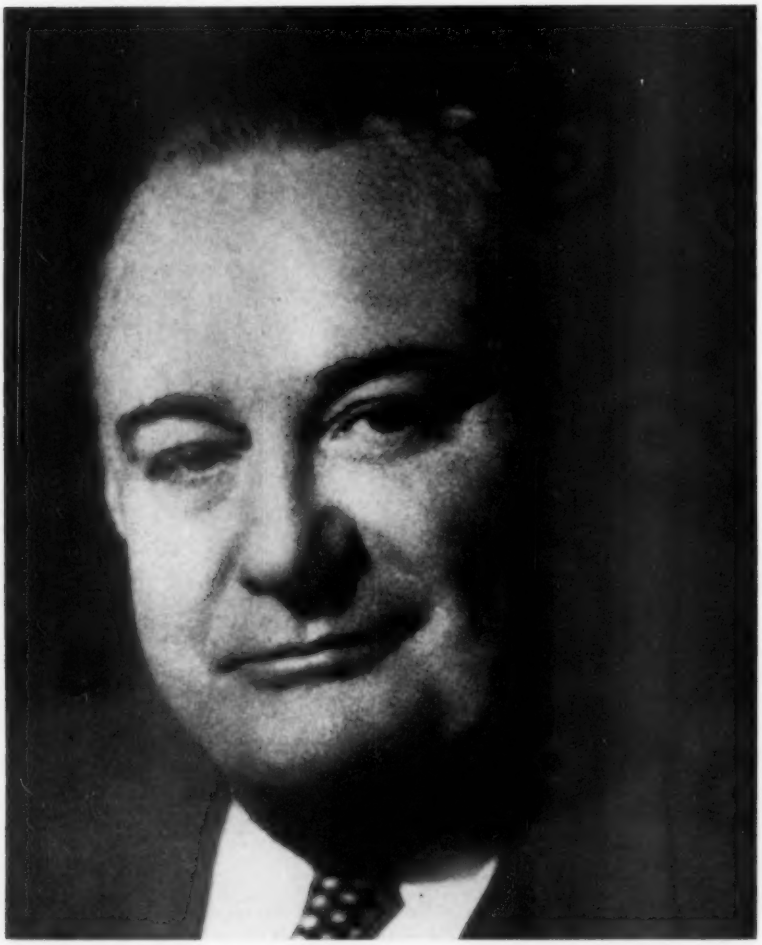
Based on a story by the Aluminum Company of America, Pittsburgh, Pa.

Fig. 1 Extending through nearly four miles of rural Texas area, this schedule 40 aluminum pipe line was buried completely devoid of protective coatings and anodes

Fig. 2 To install the line, workers joined 40-ft lengths of aluminum pipe using the argon-shielded tungsten-arc and consumable electrode welding methods

Society News

American Welding Society Elects Sander President



Clarence P. Sander

New officers of the AMERICAN WELDING SOCIETY for the 1957–58 fiscal year were introduced to the SOCIETY's membership at the opening session of the AWS Adams National Meeting, Monday, April 8, in Philadelphia. Installation of the newly elected officers will take place June 1, 1957.

New president of the SOCIETY is Clarence P. Sander, Los Angeles, Calif. Mr. Sander is general superintendent, Vernon plant, Consolidated Western Steel Div., United States Steel Corp. He previously served as first vice-president of the SOCIETY.

Other new officers are:

First Vice-president—Gustav O. Hoglund, head, Welding Section, Alcoa Process Development Laboratory, New Kensington, Pa.

Second Vice-president—Charles I. Mac Guffie, manager of marketing, Welding Department, General Electric Co., Schenectady, N. Y.

Treasurer—Harry E. Rockefeller, manager, Electric Welding, Linde Air Products Co., New York, N. Y.

Elected directors-at-large are:

James F. Deffenbaugh, chief electrical engineer, Federal Machine & Welder Co., Warren, Ohio; Alfred E. Pearson, chief welding engineer, Ingalls Iron Works Co., Birmingham, Ala.; Clarence M. Styer, Pacific Car & Foundry Co., Seattle, Wash., and Robert M. Wilson, Jr., welding specialist, Development and Research Division, International Nickel Co., Bayonne, N. J.

The following will serve as district directors:

New England (District 1)—Sidney Low, supervising engineer, Research & Development Laboratory, Chapman

Gustav O. Hoglund
First Vice-President

Charles I. MacGuffie
Second Vice-President

Harry E. Rockefeller
Treasurer

DIRECTORS AT LARGE

J. F. Deffenbaugh

A. E. Pearson

C. M. Styer

R. M. Wilson, Jr.

DISTRICT DIRECTORS

Sidney Low
District 1

H. E. Miller
District 3

Lew Gilbert
District 5

A. F. Chouinard
District 7

P. V. Pennybacker
District 9

C. B. Robinson
District 11

Valve Mfg. Co., Indian Orchard, Mass.

North Central (District 3)—Harry E. Miller, chief manufacturing engineer, Coil Div., Carrier Corp., Syracuse, N. Y.

East Central (District 5)—Lew Gilbert, publishing director, Industry and Welding, Telenews Productions, Inc., Cleveland, Ohio.

West Central (District 7)—Alfred F. Chouinard, manager, Research and Development Department, National Cylinder Gas Co., Chicago, Ill.

Southwest (District 9)—Percy V. Pennybacker, supervising field engineer, Bridge Div., Texas Highway Dept., Austin, Tex.

Northwest (District 11)—Charles B. Robinson, supervising welding engineer, Air Reduction Pacific Co., San Francisco, Calif.

The district representatives who will serve on the National Nominating Committee for the 1958–59 term will be as follows:

E. F. Nippes, Rensselaer Polytechnic Institute, Troy, N. Y. (No. 1); E. E. Goehringer, Lincoln Electric Co., Drexel Hill, Pa. (No. 2); R. J. Barr, Rochester Steel Treating Works, Rochester, N. Y. (No. 3); E. C. Miller, Union Carbide Nuclear Co., Oak Ridge, Tenn. (No. 4); E. W. Rowlands, Griscom-Russel Co., Massillon, Ohio (No. 5); J. R. Stitt, R. C. Mahon Co., Detroit , Mich. (No. 6); L. L. Baugh, Allis-Chalmers Mfg. Co., Springfield, Ill. (No. 7); M. L. Powers, Linde Air Products Co., Kansas City, Mo. (No. 8); C. E. Russell, J. B. Beaird Co., Inc. Shreveport, La. (No. 9); S. R. Lanier, Southwest Bldg. & Mfg. Co., Alhambra, Calif. (No. 10); W. J. Erichsen, Westinghouse Electric Corp., Sunnyvale, Calif. (No. 11).

●

In addition to the newly elected candidates, the following national officers will continue completion of their terms, thereby sharing the responsibility of guiding the destinies of the Society during the 1957–58 fiscal year:

Honorary Life Director: Comfort A. Adams; *Directors at large:* J. H. Blankenbuehler, F. H. Dill, G. E. Linnert, Gordon Parks, E. D. Peters, F. H. Stevenson, J. L. Wilson and R. J. Yarrow; *District Directors:* D. B. Howard (No. 2), E. C. Miller (No. 4), Keith Sheren (No. 6), F. G. Singleton (No. 8), and C. L. Breese (No. 10); *Junior Past Presidents:* F. L. Plummer, J. H. Humberstone and John J. Chyle.

Warner & Swasey Becomes A.W.S. Sustaining Member

The Warner & Swasey Co., Cleveland, Ohio, founded in 1880 by Worcester R. Warner and Ambrose Swasey, is probably best known as the manufacturer of the most versatile of all machine tools—the turret lathe—but it has rounded out its line to include automatic machines and other high-quality equipment.

One of its products is the "Gradall," an earthmoving machine of great versatility, used widely in the construction industry.

The company also manufactures textile machinery, used by producers of woolens, worsteds and synthetic materials.

Another product for which the company is famous is its great telescopes which are used in research programs by leading observatories in this country and abroad. The precision embodied in those huge instruments had been built into all of the company's products.

Dr. J. C. Hodge is the Sustaining Member representative.

AT JANUARY MEETING OF DISTRICT NO. 7 SECTION OFFICERS

Those present at the Jan. 30, 1957 meeting of District No. 7 Section Officers were, left to right, A. F. Chouinard, District director; L. L. Baugh, Sangamon Valley Section, G. A. Rehm, Sangamon Valley Section; G. O. Fruit, Iowa-Illinois Section; H. Schwartzbart, Armour Research Foundation; H. H. Comstock, Chicago Section; F. E. Theiler, Madison Section; W. C. Lilly, Chicago Section; F. J. Harencki, Milwaukee Section; and J. Bland, Chicago Section.

West Central District Officers Meet in Chicago

The Executive Committee of the West Central District held a dinner meeting in conjunction with the 3rd Annual Midwest Welding Conference in Chicago on January 30th.

A. F. Chouinard, district director, explained to the section officers some of the plans concerning the proposed membership classes in the SOCIETY. The section officers also discussed the work their sections are doing in assisting the National Educational Committee Program.

Many other items that were pertinent to the operation of the Sections were discussed. Everyone present agreed that these Executive Committee meetings that are held every 4 or 5 months are of great benefit in helping the section officers in guiding their Section Activities.

AWS DIRECTORS-AT-LARGE

Term Expires	1957	1958	1959
	R. W. Clark	F. H. Dill	J. H. Blankenbuehler
	J. W. Mortimer	E. D. Peters	G. E. Linnert
	Hal Savage	J. L. Wilson	Gordon Parks
	R. L. Townsend	R. J. Yarrow	F. H. Stevenson

AWS DISTRICT DIRECTORS

District No. 1 • New England	Sidney Low	District No. 7 • West Central	A. F. Chouinard
District No. 2 • Middle Eastern	D. B. Howard	District No. 8 • Midwest	F. G. Singleton
District No. 3 • North Central	C. E. Jackson	District No. 9 • Southwest	P. V. Pennybacker
District No. 4 • Southeast	E. C. Miller	District No. 10 • Western	C. L. Breese
District No. 5 • East Central	Lew Gilbert	District No. 11 • Northwest	C. M. Styer
District No. 6 • Central	Keith Sheren		

OTHER DIRECTORS

Honorary Life Director	C. A. Adams	Junior Past-President	F. L. Plummer
Junior Past President	C. H. Jennings	Junior Past-President	J. H. Humberstone

Fenton Promoted to Assistant Technical Secretary

Edward A. Fenton has recently been promoted to the position of assistant technical secretary of the AMERICAN WELDING SOCIETY, effective Jan. 1, 1957.

Mr. Fenton attended the College of the City of New York and graduated in 1947 with a degree of Bachelor of Mechanical Engineering. He later attended the Polytechnic Institute of Brooklyn and received the degree of Master of Metallurgical Engineering.

From 1947 to 1954, Mr. Fenton held positions of a welding and metallurgical nature in the shipbuilding, railroad, oil refinery, chemical plant and jet engine industries. During the past 3 years, he has served on the SOCIETY's Staff as assistant to the technical secretary.

Edward A. Fenton

Mr. Fenton is a member of the AMERICAN WELDING SOCIETY, American Society for Metals, Sigma Xi and is a registered professional engineer in the State of New York.

Sustaining Membership Assumed by Ladish Co.

Ladish Co., Cudahy, Wis. has recently joined the ranks of Sustaining Members of the AMERICAN WELDING SOCIETY.

The firm's products include: (1) drop forgings up to 10,000 lb in all forgeable material specifications, (2) seamless or welded rolled rings in rectangular and contour cross sections, in weights up to 60,000 lb and diameters up to 20 ft, (3) complete line of pipe fittings; welding fittings, screwed and socket welding fittings and forged flanges.

Executive offices and main plant are located in Cudahy, Wis. Branch plants are located in Kenosha, Wis., Los Angeles, Calif. and Brantford, Ontario, Canada.

C. A. Furgason, vice-president in charge of research and metallurgy, is the Sustaining Member representative.

IMPROVED MAGNETIC STARTER has quick response bi-metallic thermal overload relays which sense current changes and to help prevent motor burnout in case of sustained overloads or accidental single phasing. Large starter contacts are long-lasting, won't chatter.

ANNOUNCING A NEW LOOK IN M-G WELDERS!

New General Electric M-G Set Speeds Welding with Stable, Penetrating Arc—In Any Position

General Electric's new motor-generator welder gives you the stable, penetrating arc you need to get even those tough, out-of-position welding jobs done faster and better.

The secret? General Electric's NEW laminated frame welding generator, working in combination with a unique transformer reactor.

The arc is stable because this new reactor provides excellent control of current surges and assures immediate high recovery voltage at all settings. No need to worry about costly delays caused by electrode freezing or popouts.

A high level of "arc force," with the stable arc, makes the General Electric m-g set ideal for a wide variety of industrial applications, including light, medium, and heavy d-c metal-arc and inert-arc welding.

And here are just a few other reasons why the new G-E motor-generator welder answers your need for high-quality welds in less time and at less cost.

EASY TO USE—current is not sensitive to changes in line voltage—once the simple current setting has been made, no further adjustment is necessary. Arc has quick response and good control in all positions.

FUNCTIONAL DESIGN—two welding sets can be installed in the space normally required by one, saving valuable floor area—brushes can be changed while welders are stacked—cooling air enters the ends, exhausts front and back, to prevent recirculation.

LESS MAINTENANCE—constant pressure brush springs give maximum brush life—rubber-mounted, extra-width, pre-lubricated bearings require no maintenance—motor windings are Mylar* insulated and Dri-Film† coated to help prevent insulation failures—heavy-duty motor starter contacts last for years.

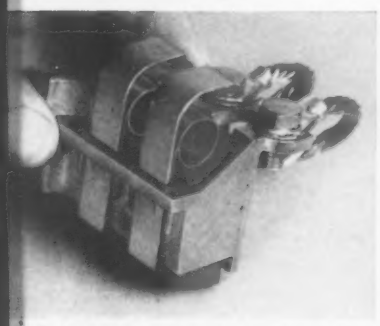
General Electric's new d-c motor-generator sets are available in both 300 and 400 ampere designs, rated 40 volts, 60% duty cycle. For more information about them, contact your nearby General Electric Welding outlet, listed in the yellow pages of your telephone book. Write for descriptive bulletin GEA-6423 to Section 711-8 General Electric Company, Schenectady 5, New York.

*Reg. Trademark of DuPont Co.

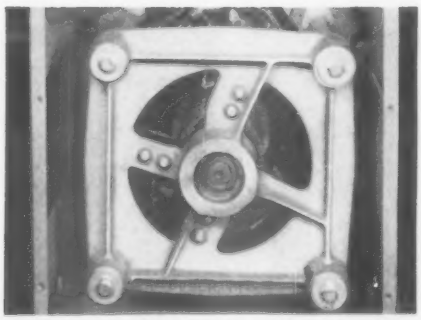
†Reg. Trademark of General Electric Co.

Progress Is Our Most Important Product

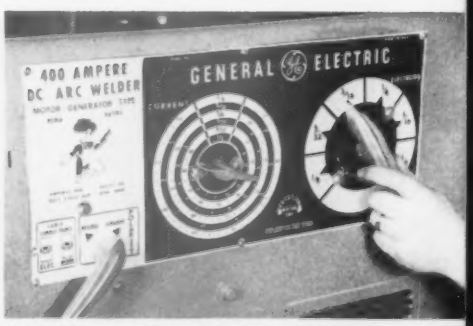
GENERAL ELECTRIC



CONSTANT-FORCE brush springs need no adjustment; give the correct constant pressure during brush life. Removable spring clips permit easy replacement of brushes.



STURDY CONSTRUCTION results from one inch diameter steel rods which link the bearing housings with welded generator and motor frames. Sturdy ¼" angles are welded to the generator frame to provide a solid base.



DUAL CONTROL DIAL is fully calibrated, easy to read. Just select electrode size on Electrode Selector, then set sensitive long-scale current control for desired welding current.

Section News and Events

as reported to Catherine O'Leary

SECTION QUIZ PROGRAM

Fort Wayne, Ind.—On March 21st the *Anthony Wayne* Section held a Section quiz program at the Happy Ranch House. Section members prepared questions to be presented to the panel of experts The purpose of the quiz was to help prepare the panel to retain the Detroit Section's trophy on April 19th and to win the Indianapolis Section's trophy on April 26th.

ATOMIC REACTORS

Birmingham, Ala.—E. C. Miller AWS, inspection engineer, Oak Ridge National Laboratory, was the speaker at the March 12th meeting of the *Birmingham* Section held at Gulas Restaurant. Mr. Miller's subject was "Metals and Their Fabrication for Atomic Power." Mr. Miller is district director of the Southeastern District.

POROSITY IN STEEL

Bridgeport, Conn.—At the March 21st dinner meeting of the *Bridgeport* Section, held at the Fairway Restaurant and the General Electric Co., J. T. Ballass AWS, of the Electric Boat Division, General Dynamics Corp., Groton, Conn., gave a very interesting talk, accompanied by slides. He spoke on porosity in mild steel welding using metal-arc inert-gas welding on killed and semikilled steels.

SECTION MEETING CALENDAR

JUNE 1

COLUMBUS Secton. Ladies Night.

JUNE 8

CHICAGO Section, 7:00 A.M. starting time. Golf outing. Nordic Hills Country Club, Itasca, Ill. (members only).

JUNE 11

DAYTON Section. Annual Picnic. Inland Activities Center.

JUNE 20

SHREVEPORT Section. Dinner 7:00 P.M. Meeting 8:00 P.M. Colonial Room, Captain Shreve Hotel, Shreveport, La. "The Use of X-Ray to Control Weld Quality," Harold Hovland, Industrial X-Ray Engineers.

JUNE 24

SAN FRANCISCO Section. "Welding in Fabricating Using T-1 Steel"—a story of the Carquinez Bridge. J. L. Beaton, California Division of Highways.

Editor's Note: Notices for August 1957 meetings must reach Journal office prior to June 1, so that they may be published in July Calendar. Give full information concerning time, place, topic and speaker for each meeting.

LOW-HYDROGEN ELECTRODES

Chicago, Ill.—Over one hundred members and guests of the *Chicago* Section were present on February 15th in the auditorium of the People's Gas, Light and Coke Co. to hear Richard K. Lee AWS, of the Alloy Rods Co., York, Pa. give an illustrated talk covering the history, development and uses of low-hydrogen electrodes as well as the make-up of modern electrodes. He also discussed the effects of hydrogen in welds.

A pre-meeting movie, shown through the courtesy of Canadian Travel Film Library, was enjoyed by the entire group.

STAINLESS STEEL

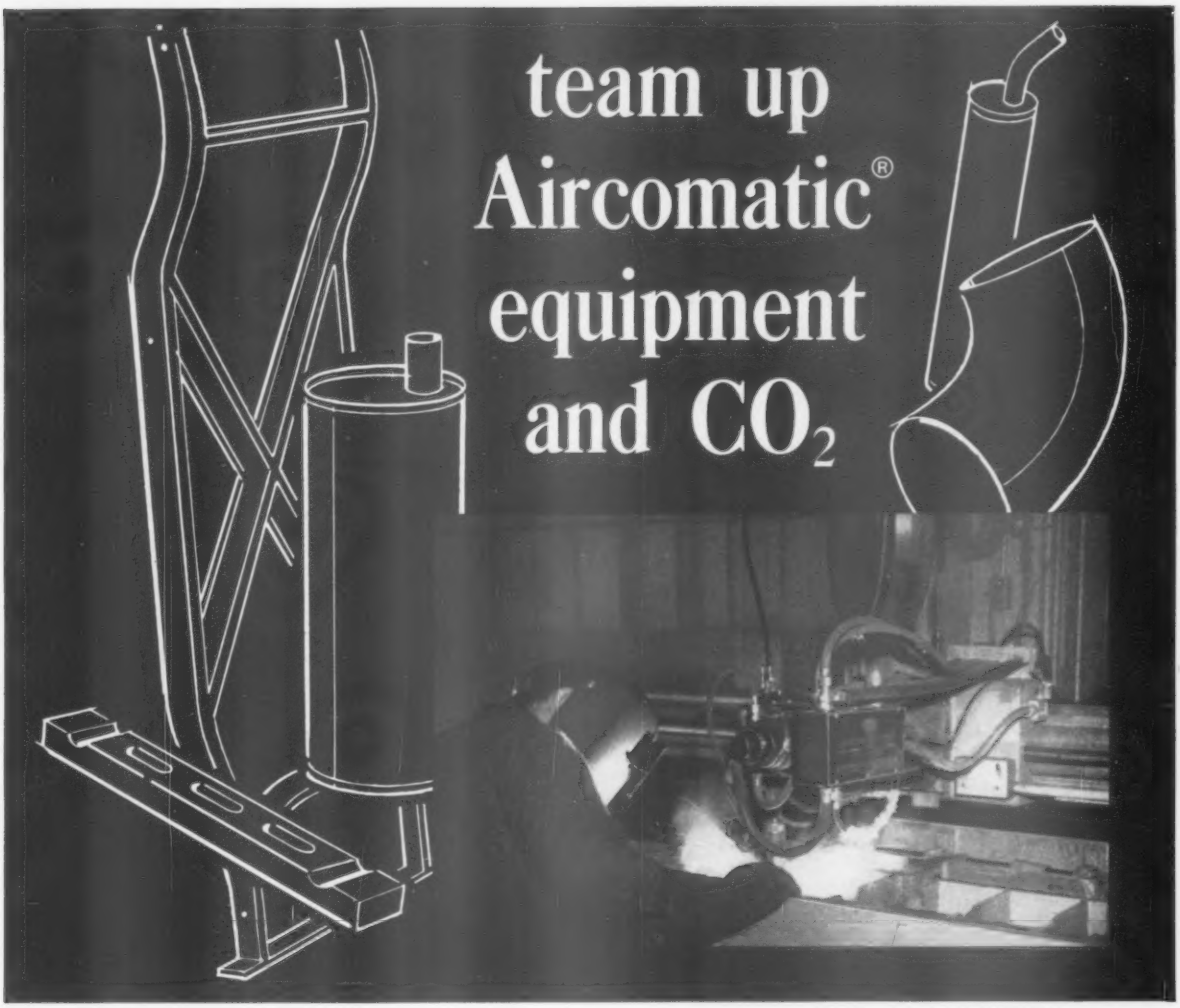
Cincinnati, Ohio—Guest speaker at the February 26th meeting of the *Cincinnati* Section held in the Engineering Society of Cincinnati was George E. Linnert AWS, of the Armco Research Laboratories, Baltimore, Md. Mr. Linnert's subject was "Welding Precipitation-Hardening Stainless Steel."

Mr. Linnert pointed out the wide range of use for precipitation-hardening stainless steel, from carpenter hand-saws to supersonic aircraft. These steels are used for their high strength-to-weight ratios. Much attention has been focused on these steels because of the marked differences in weldability and the newness

CLEVELAND SECTION HONORS PAST CHAIRMEN

Receiving past chairmen's awards at the March 13 meeting of Cleveland Section are (left to right) F. L. Plummer (1938–40), J. C. Wyss (1950–51), J. F. Maine (1940–42), C. T. Elder (1949–50) and R. J. Kriz (1942–44)

Also among those who received past chairmen's awards were (left to right) Ross Yarrow (1944–46), J. B. Austin (1951–52), K. C. Thornton (1946–47) and Allen Stern (1955–56)



for low cost inert gas arc welding of mild steel

The Aircomatic arc welding process using carbon dioxide gas as the shielding medium, means high economy and speed in certain mild steel welding applications.

Fabricators of mild steel products such as car frames, fuel tanks, water heaters, trailer frame supports and pedal levers report outstanding results and substantial savings through this new technical development.

This combination of Aircomatic equipment (manual or automatic) and CO_2 is particularly recommended for high production work where the faster welding speeds and the inexpensive shielding gas will most benefit the cost conscious user. It is an ideal process for single pass applications and multiple pass applications. Joining sections of large diameter steel pipe is but one example.

If you weld mild steel, investigate the possibilities and advantages of using the Aircomatic process in your particular operation. Complete information and literature is available. Write Airco today!

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Products of the divisions of Air Reduction Company, Incorporated, include: **AIRCO** — industrial gases, welding and cutting equipment, and acetylenic chemicals • **PURECO** — carbon dioxide — gaseous, liquid, solid ("DRY-ICE") • **OHIO** — medical gases and hospital equipment • **NATIONAL CARBIDE** — pipeline acetylene and calcium carbide • **COLTON** — polyvinyl acetate, alcohols, and other synthetic resins.

RESISTANCE WELDING PANEL AT COLUMBUS SECTION

Partial view of the more than 50 members and guests who attended the March 8th meeting of Columbus Section

Assistant Dean G. M. Lawrence of Ohio State University awards certificate to R. M. Endsley. R. C. McMaster, professor of welding engineering, is at right.

C. LaPlante describes fabrication of automatic washing machine housing. Left to right, are W. Kahkola, R. Warrender, Mr. LaPlante, Prof. McMaster, Bob Newton and Jack Cook.

of the procedures employed in welding and heat treating.

The available grades are classified according to their microstructure in the hardened condition and (1) single treatment martensitic, (2) double treatment martensitic, (3) austenitic, and (4) austenitic-ferritic. These categories are produced by careful proportioning of chromium-nickel composition and the addition of alloying elements like aluminum, copper, molybdenum or titanium. The retention of these alloying elements in the welding process is essential for suitable welding procedures.

PAST CHAIRMAN'S NIGHT

Cleveland, Ohio—One hundred and two members and guests of the *Cleveland* Section were present on March 13th for "Past Chairman's Night". They also heard Fred L. Plummer AWS, director of engineering for the Hammond Iron Works of Warren, Pa.

Following the dinner, at which time the Past Chairman's Service Certificates were presented, the meeting was turned over to the speaker of the evening, Mr. Plummer, who gave an illustrated talk on design for welded-plate fabrication. Mr. Plummer emphasized those design problems having to do with fabrication and erection and welding of storage and process vessels. Several types of field-erected vessels were used to illustrate joint design and selection of welding electrodes, equipment, procedures and sequences. Testing and inspection methods were also discussed.

INERT-GAS WELDING AND CUTTING

Denver, Colo.—Thirty-one members and guests attended the regular monthly dinner meeting of the *Colorado* Section held on March 12th in the Festival Room of the Oxford Hotel. Dave Kard of the Kard Iron Works showed color slides of a variety of mine cars made by his company and gave a verbal description of their operation.

C. A. McClean AWS, of the Air Reduction Sales Co., New York, addressed the group on the subject of "Gas-Shielded Arc Welding and Cutting," accompanied by slides and charts. Mr. McClean's presentation was very well received and proved so interesting that an unusually long question period followed.

PANEL DISCUSSION

Columbus, Ohio—The *Columbus* Section meeting held on March 8th at Riverside Restaurant consisted of a panel discussion on "Special Applications of Resistance Welding" and the presenting of certificates to 20, out of 36, men who completed the "Conference Course on Nondestructive Testing." The course was presented by the Department of Welding Engineering, the College of Engi-

KUGLER SPEAKS ON BRAZING BEFORE DETROIT SECTION

Seated at speakers' table are, next to one another, dinner speaker E. L. Bridge (dark suit, with hands together), Section Chairman Bill Smith (center), and technical speaker A. N. Kugler (second from right)

Mr. Kugler, who spoke on brazing and related filler metals, stresses a point with the aid of notes on blackboard.

neering, The Ohio State University, and was remarkable, in that all the men who started the course also completed it. The certificates were presented by Assistant Dean George M. Lawrence of Ohio State University, College of Engineering. The 16 men who could not be present at this meeting received their certificates by mail.

The panel discussion was moderated by Prof. Robert C. McMaster of Ohio State University. It covered resistance welding applications, from automatic washing machines to contacts for refrigeration control relays. Guest panel member was Will Kahkola, sales engineer for the Weltronic Co. Other members of the panel, all members of the Columbus Section, were Frank Williamson, Welding Supply Service; Ralph Warrender, Westinghouse Electric Co., Clarence LaPlante, Clark Grave Vault Co.; Bob Newton, Ranco Inc.; and Jack Cook, Ohio State University. A total of 54 members attended the dinner and meeting.

ARC CUTTING

Dayton, Ohio—A dinner meeting of the *Dayton* Section, with 40 members and guests attending, was held at Longo's Spaghetti House on March 12th.

The agenda consisted of a social hour from 6:00 P.M. to 7:00 P.M., followed by dinner at 7:00 P.M. and by the regular meeting at 8:00 P.M.

The regular meeting opened with a "Past Chairman's Pin" presentation to Robert Hous, followed by a short film.

The main speaker for the evening, Myron Stepath AWS, of Arcair Co., Lancaster, Ohio, outlined the carbon arc-air cutting process and its uses, aided with 35 mm slides.

The meeting was adjourned at 9:30 P.M., following which an officers' meeting was held.

BRAZING

Detroit, Mich.—The regular monthly meeting of the *Detroit* Section was held at the Rackham Building (Engineering Society of Detroit) on Friday evening, March 8th.

The usual good dinner was served to 30 members and guests who heard a very good talk by Ernst L. Bridge, Register, Wayne County Juvenile Court. Mr. Bridge spoke of the Detroit juvenile situation, and the dinner guests would have kept him there for a couple of hours but for the fact that the technical session was to follow.

The technical meeting was held in the small auditorium with about 100 members and guests in attendance. The guest speaker was A. N. Kugler AWS, chief sales engineer of Air Reduction Sales Co., New York office. Mr. Kugler talked for an hour on brazing. He outlined the classes of filler metals and talked on the various joints. There were a number of questions from the floor, which created a good general discussion of various shop problems.

SHIPYARD WELDING PROBLEMS

Houston, Tex.—The *Houston* Section held its regular monthly dinner meeting on February 27th in the Ben Milam Hotel. Seventy-eight members and guests were present at the meeting to hear O. H. Haunschild AWS, assisted by Paul Reitz AWS both with the Levingston Shipbuilding Co., Orange, Tex. Mr. Haunschild discussed some of the welding problems they are experiencing in the shipyard in relation to marine construction and repair, along with off-shore drilling rig construction.

An after-dinner feature was the showing of a film entitled "Operation Ivy" produced by the U. S. Air Force and shown through the courtesy of the Civilian Defense of Houston.

Tempilstik° FOR ALL HEAT-DEPENDENT OPERATIONS

looks like a crayon... marks like a crayon... tells temperatures like a precision instrument!

Available in these Temperatures (F.)

113	375	1000
125	388	1050
138	400	1100
150	413	1150
163	425	1200
175	438	1250
188	450	1300
200	463	1350
213	475	1400
225	488	1450
238	500	1500
250	550	1550
263	600	1600
275	650	1650
288	700	1700
300	750	1750
313	800	1800
325	850	1850
338	900	1900
350	950	1950
363		2000

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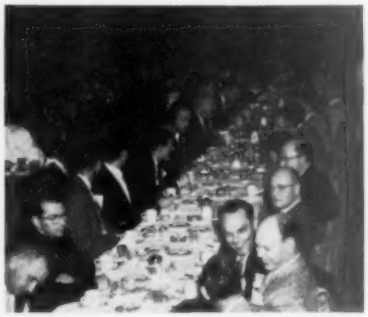
LOCKHEED VISITED BY AIRCRAFT AND ROCKETRY PANEL

At speakers' table are, left to right, W. Raabe and D. J. Gribbon of Lockheed Aircraft; M. Ochieano, L. West, and H. Eubanks of Panel

Mr. Gribbon, chief manufacturing engineer, welcomes members and guests of Aircraft and Rocketry Panel prior to tour held on March 14th



Two views of the large crowd enjoying dinner in the "Sky Room" at Airport before starting on tour of plant

INERT-GAS WELDING AND CUTTING

Kansas City, Mo.—A total of 63 members and guests of the *Kansas City* Section enjoyed a fine dinner on March 14th at the Golden Ox Restaurant. A fine coffee speaker was "Doc" Howard of Weldon Laboratory who discussed the educational program for engineers at the University of Kansas City.

The main speaker of the evening was Charles McClean AWS, of Air Reduction Sales Co., N. Y., who discussed the inert-arc welding and cutting processes. He had slides and numerous samples of inert-gas welds which proved very interesting.

STAINLESS STEELS

Port Washington, L. I.—A joint dinner and technical meeting of the *Long Island* Section and the American Society for Metals was held on March 20th at Patricia Murphy's Candlelight Restaurant in Port Washington.

The guest speaker was George E. Linnert AWS, research welding metallurgist, Armco Steel Corp.

Mr. Linnert gave an excellent and informative talk on "Welding Precipitation-Hardening Stainless Steels." This talk was taken from the 1956 Adams Lecture which Mr. Linnert delivered in Cleveland last October and which appeared in the January 1957 issue of THE WELDING JOURNAL. A simplified description of the metallurgical behavior of these steels was given before attempting to cover welding.

PLANT TOUR

Burbank, Calif.—The March 14th meeting of the *Aircraft and Rocketry Panel* of the *Los Angeles* Section featured a plant tour of the Lockheed Aircraft Co's. facilities in Burbank, one of America's leading manufacturers of commercial and military aircraft.

One hundred and sixty members and guests gathered at the "Sky Room" located at the Lockheed Air Terminal adjacent to the Lockheed Plant, prior to the tour, to enjoy cocktails and dinner. Following dinner, a short business session was held, at which time the chairman introduced such guests as A. H. Peterson, group engineer for Lockheed; Wallace Raabe, public relations director; and Daniel J. Gribbon, chief

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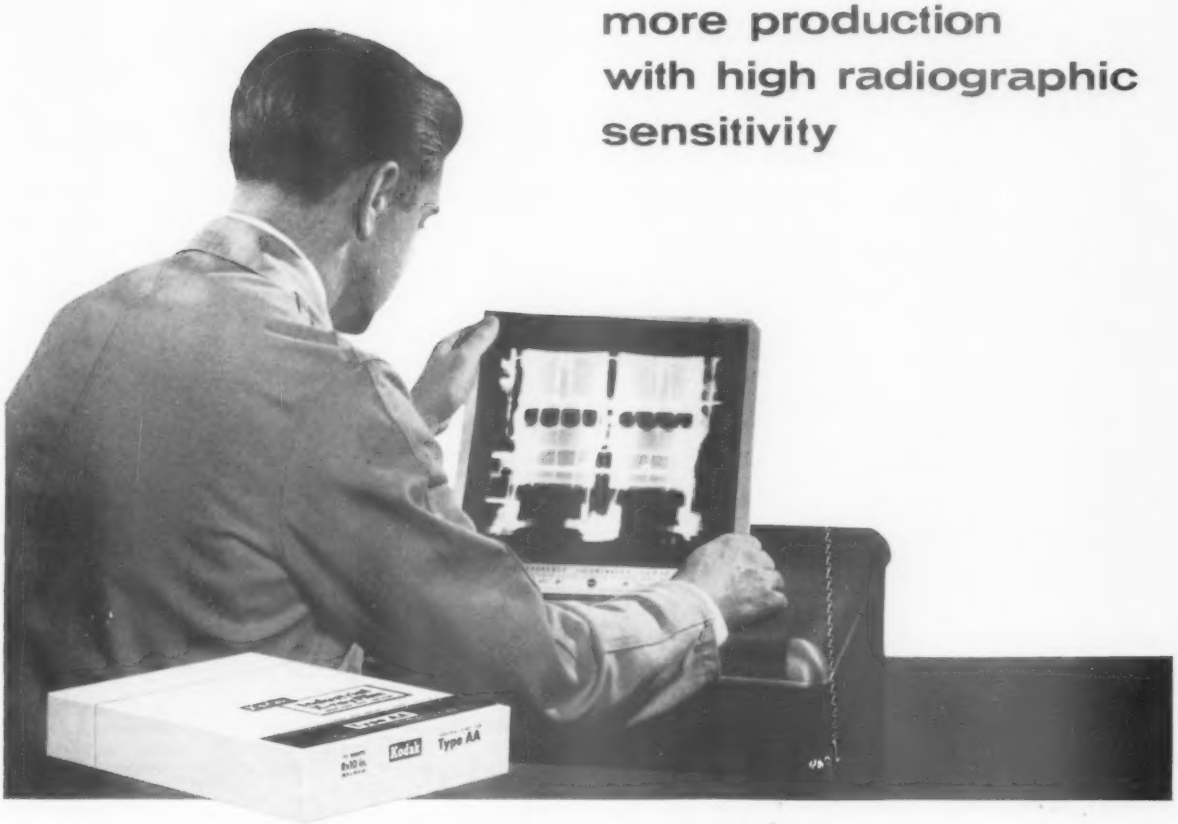

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manufacturing engineer. Mr. Gribbon gave a short welcoming address, followed by a brief outline of the tour.

The meeting was adjourned at 8:45 P.M., at which time the members and guests were taken in small groups through the manufacturing facilities. Acting as guides were the Messrs. Fish, Warren, Hodson, McBride, Thayer, Meggs, Ezan, Dolero and Ochicano; all members of the manufacturing engineering group at the Lockheed facilities. Owing to the size of the Lockheed Plant, the tour was limited to plant A in which the commercial airplanes are produced. Here every one had a chance to see the largest one-piece wing jig in the aircraft industry. The wings fabricated were for the Model 1649 airplane. Skins for these wings were machined from one long-extruded plate, assembled in panel jigs and then placed in the main jig. Members and guests were also taken through the Hall of Giants to observe the huge milling equipment required for the milling of skins, large Hufford stretch presses and an 8000 ton hydraulic press. In concluding the tour, they were taken through the mockups of the Electra airplane. The tour was very well conducted by the Lockheed personnel, and all members and guests enjoyed what proved to be a very interesting, educational, and well spent evening.

PLANT VISIT

Louisville, Ky.—Ninety-six members and guests of the *Louisville* Section were privileged to visit the local government arsenal on February 26th. Here, the Navy manufactures, on a production basis, their five-inch 54-caliber gun. The group saw the entire fabrication of the tube, mount and shields of the Navy's single and twin-mount five-inch guns. The best of equipment, material and man-power are needed to produce a weapon of this sort. The machinery, from the small drill press to the large milling machine and planers, was of the highest quality. The center of attraction was an X-ray machine, the largest in the country, that is used to verify the quality of the material and the welded joints.

Much was learned from this visit that will benefit all those attending.

TOOL AND DIE WELDING

Louisville, Ky.—The *Louisville* Section held its March 26th meeting at the Kentucky State Fair & Exposition Center, Louisville, Ky. Frank Kessler AWS, of the Eureka Tool and Die Co., Detroit, Mich., gave an extemporaneous talk on "Tool and Die Welding." Slides were used to illustrate Mr. Kessler's presentation.

An AWS monogramed cigarette lighter was presented to the speaker as a token of appreciation.

WELDING PROCESSES

Baltimore, Md.—The March 15th meeting of the *Maryland* Section was held at the Engineer's Club in Baltimore.

Technical speaker was Orville T. Barnett AWS, assistant manager, Armour Research Foundation of Illinois Institute of Technology, who spoke on "Which Welding Process and Why."

NEW DEVELOPMENTS

Milwaukee, Wis.—Thomas McElrath AWS, of Linde Air Products Co., Newark, N. J., gave a very interesting talk at the March 22nd meeting of the *Milwaukee* Section held at the Ambassador Hotel with an attendance of 97 at dinner and 105 at the meeting.

Mr. McElrath has spent the last twelve years in research on inert-gas welding, and has an excellent background of knowledge and experience to draw from.

He pointed out the various steps that occur in the development of a welding process, from the birth of an idea, through the various stages of development, until it finally becomes a standard commercial piece of welding equipment.

He also discussed some of the newer items of equipment for tungsten-arc welding, as well as the inert-gas-shielded metal-arc process.

He also pointed out the advantages of the use of new gas mixtures for these processes, and gave examples of many applications which illustrate the rapid growth of these newer welded methods in industry.

Mr. McElrath's talk was illustrated by very excellent color slides, and his most informative talk was well received by the Milwaukee Section.

SAFETY IN WELDING

New York Mills, N. Y.—The *Mohawk Valley* Section met on February 14th in the New York Mills School. The speaker of the evening was A. N. Kugler AWS, welding engineer, Air Reduction Sales Co., New York, N. Y. His topic was "Safety in Welding." Preceding the technical talk, a sound movie "Whatever We Do," in color, was presented. It explained the processes of extracting and separating oxygen and hydrogen and various inert gases from the earth's atmosphere. Also, it showed how these gases are used in manufacturing many items that appear on today's market.

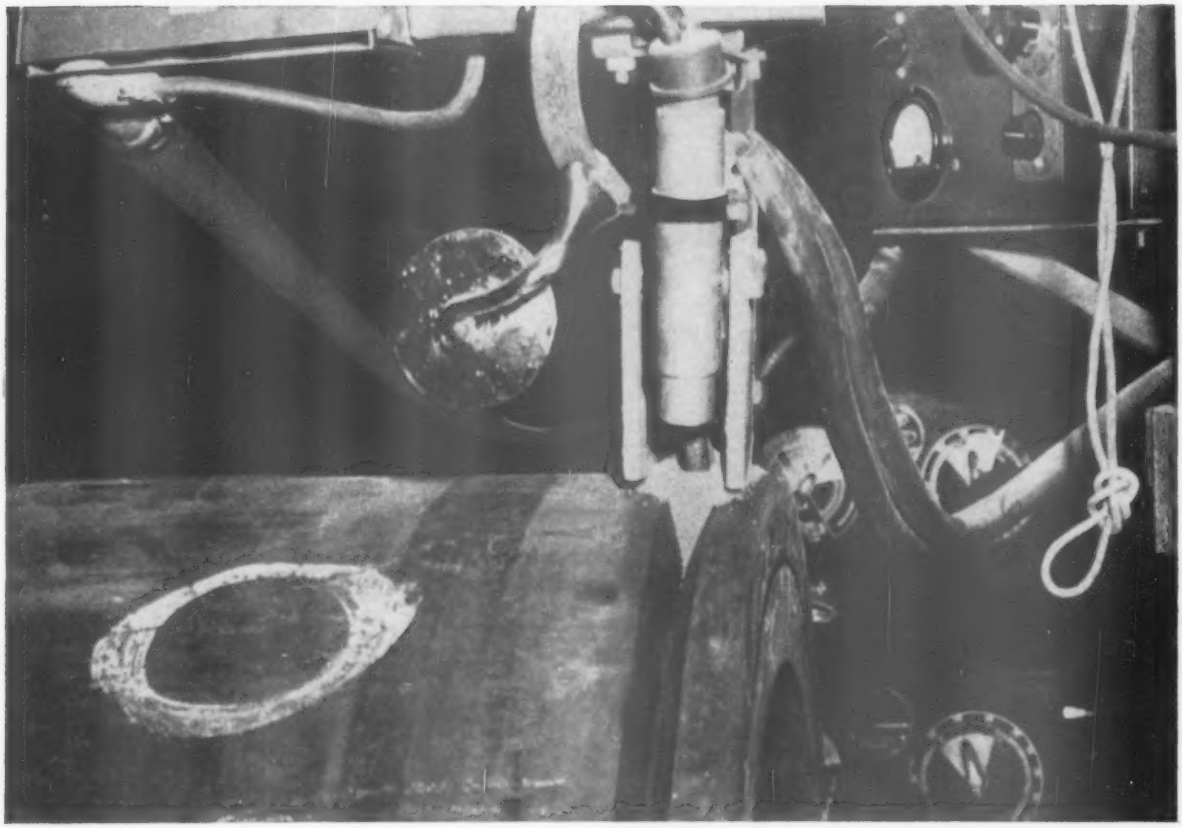
During his technical talk, Mr. Kugler presented slides dealing with safety habits and precautions in the everyday use of oxyacetylene and arc-welding equipment.

Following the talk and pictures, there was a very interesting question and answer period.

NEW JERSEY SECTION ADDRESSED BY KALTENHAUSER

Capacity audience of 120 members and guests of the New Jersey Section was on hand at the February 19th meeting.

Guest speaker R. H. Kaltenhauser presenting his talk on welding of high-temperature stainless steel.



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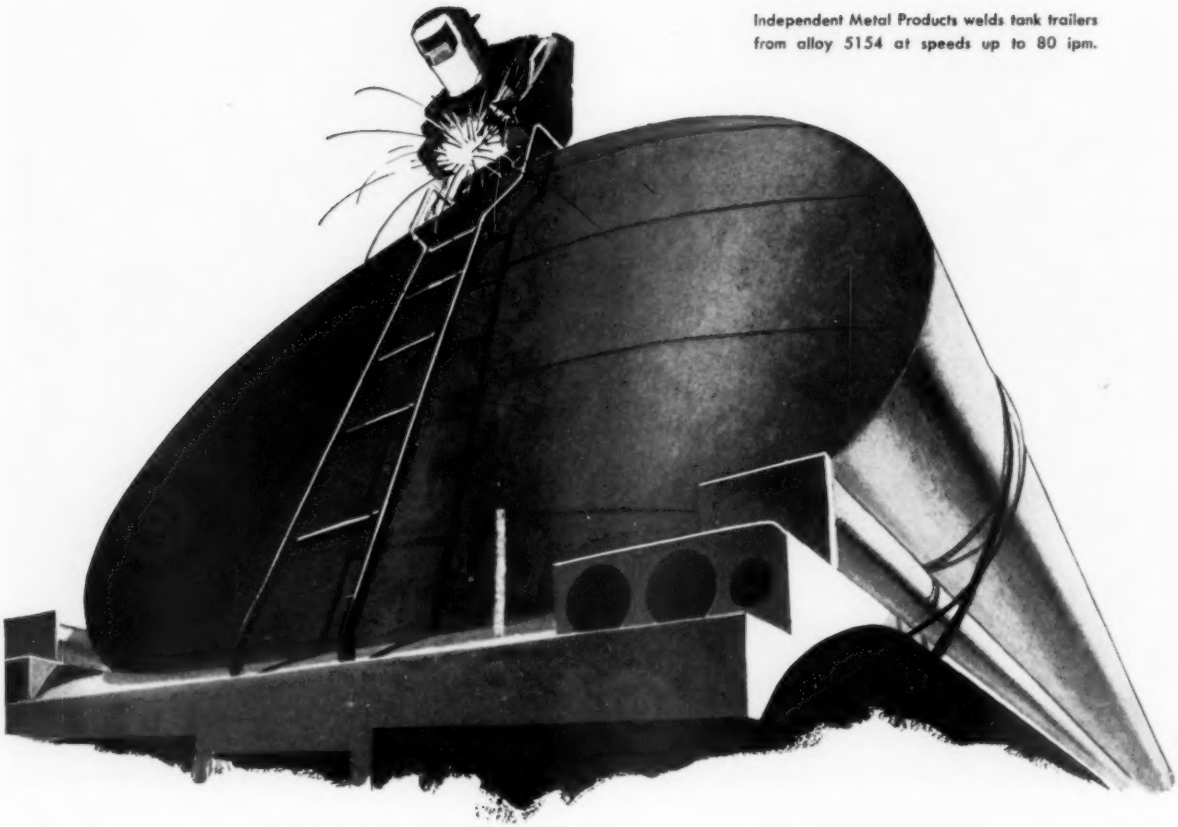

Independent Metal Products welds tank trailers from alloy 5154 at speeds up to 80 ipm.

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ALUMINUM WELDING DISCUSSED BY BAYSINGER

Guest speaker F. Robert Baysinger discussing the welding of aluminum at the March 19th meeting of the New Jersey Section

Forde Simms (left) receiving door prize from "Hank" Hoffman, program chairman.

Members and guests enjoying after-meeting get-together and snack.

RADAR NETWORK

Manchester, N. H.—The *New Hampshire* Section held its March 19th dinner meeting at the Queen City Hotel in Manchester. The program was under the direction of Robert Worrell of the Lyons Iron Works.

The highlight of the evening was the showing of a color film, "Texas Towers," by James Brodie, of the engineering firm of Anderson-Nichols Co., Inc. of N. Y. C. and Concord, N. H. Mr. Brodie described some of the problems that had to be surmounted during the engineering and construction of these vital links in our national radar defense network. He also explained the manner in which they were solved.

The number and type of questions Mr. Brodie was asked during the discussion period, was indicative of the great satisfaction that members and guests received from the speaker and his topic.

HIGH-TEMPERATURE STAINLESS STEELS

Newark, N. J.—Robert H. Kaltenhauser, research metallurgist of the Allegheny Ludlum Steel Co., was the principal speaker at the *New Jersey* Section's regular monthly dinner meeting held at the Essex House Hotel in Newark on February 19th.

His subject, "The Welding of the High-Temperature Stainless Steels," was given before a capacity audience of 120 members and guests. Mr. Kaltenhauser spoke of the constant demands by industry upon Engineers and Metallurgists to produce steels that maintain strength and resist oxidization at the higher temperatures. Describing a new group of weldable stainless steels produced by the Allegheny Ludlum Steel Co. and identified as the 200 Series, he pointed out that they retain 85 to 90% of strength up to 900° F and are used primarily as component parts for jet engines.

With the help of slides, direct comparisons were made of the chemical and physical characteristics of the 200 and 300 Series Stainless Steels.

Preceding the meeting, a film was shown entitled "And Then There Were Four." It is a story of five families involved in unsafe driving practices, one of which proves fatal.

WELDING OF ALUMINUM

Newark, N. J.—Sixty-six members and guests attended the pre-meeting dinner of the *New Jersey* Section held at the Essex House Hotel in Newark on March 19th, and approximately eight-five were present at the meeting that followed.

The meeting was preceded by an excellent color film entitled "Fly Fisherman Fly," showing how some fishermen travel by plane to the choice fishing grounds in remote parts of Canada, Maine, Minnesota and the Everglades.

F. Robert Baysinger AWS, of the Kaiser Aluminum and Chemical Corp., a graduate welding engineer of Ohio State University, and at present research engineer in the Metallurgical Research Department of the Kaiser Co., was principal speaker.

Mr. Baysinger's subject, "The Welding of Aluminum," was of interest to both production and engineering. It covered four steps:

1. History of aluminum welding: methods used from 1907 to 1956.
2. Difference between aluminum and steel: the thermal characteristics and their effect upon welding.
3. Metallurgical aspects: describing the many types of alloys available.
4. Quality welds with the inert-gas metal-arc process: causes of porosity, correct arc voltage, hydrogen and clean electrode wire and base metal.

After an active question and answer period, there followed the usual after-meeting refreshments and social get-together.

T-1 STEEL

New Orleans, La.—With some 80 members and guests in attendance, the *New Orleans* Section met on March 26th for its regular dinner meeting in the Engineers' Club of the De Soto Hotel.

Guest speaker of the evening was Leon C. Bibber AWS, chief research engineer of U. S. Steel. Mr. Bibber selected as his subject, "T-1 Steel," which he so capably presented. Along with his lecture, 16 mm and slide films were shown. The subject of "T-1 Steel" proved of great interest to everyone, particularly to the many petroleum company guests who were in attendance.

DISTORTION CONTROL

New York, N. Y.—On Tuesday, March 12th, the *New York* Section held its regular monthly meeting which was very well attended.

J. R. Stitt AWS, research and welding engineer with the R. C. Mahon Co., Detroit, Mich., was the speaker. His topic was—"Distortion and Its Control in Arc Welding."

The speaker discussed, in great detail, the difficulties encountered regarding warpage and distortion. Bridges, tanks and structures—in fact, any welded structure that is not properly set up—is subjected to distortion which sometimes can cause serious troubles. In the speaker's own company, the distortion problem has been given considerable consideration, and slides of the set-up used and of the finished product have been taken and studied, for future guidance.

Mr. Stitt showed these slides and explained the methods used in their own shop. He urged the audience to ask questions as the lecture progressed, and many took advantage of this opportunity, making the evening an interesting and beneficial one.

Before the main talk and directly after the dinner, R. Schultz, a representative of the brokerage firm of Merrill, Lynch, Pierce, Fenner and Beane, gave a short dissertation on proper investment of money by purchasing stocks and bonds.

The meeting was held at Victor's Restaurant and an excellent dinner was served prior to the talks.

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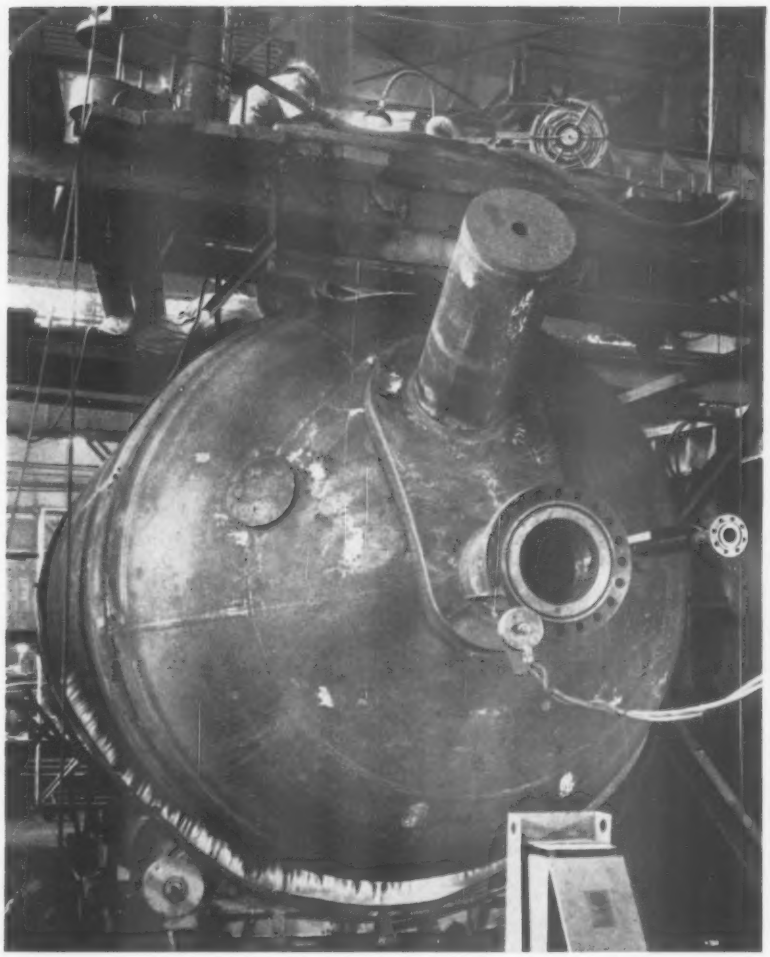
WELDING INSTRUCTIONS

New York, N. Y.—During the months of February and March, four lectures were arranged by the *New York* Section, primarily as a Welding School for the New York Building Inspectors. Three of the lectures were given at the Air Reduction Sales Co. offices. The last meeting was more of a vocational nature and was held at the New York Trade School where actual setup and welding was demonstrated. In addition, finished welds were inspected and tested and an interpretation was given of the quality of work as indicated by the test specimens.

Excellent speakers presented the lectures and an unexpected overflow audience was in attendance. Many complimentary letters have been received from individuals as well as from the New York City Building Department.

The arrangements were made by Al Seiden, of the New York Section. Stan Walter of the Air Reduction Sales Co. and J. E. Mooney of the New York Trade School ably assisted Mr. Seiden. Other members of the New York Section also helped to some extent.



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FRACTURE DATA

Buffalo, N. Y.—Fifty-one hardy members of the *Niagara Frontier* Section who braved the typical January weather were treated to a well organized analysis of fracture data concerning steel used primarily in ship construction, by Peter P. Puzak, U. S. Naval Research Laboratory, at the January 24th meeting held at Mann's 300 Club.

Testing techniques were outlined, primarily testing designed to reproduce failures similar to those which have actually occurred. The arc-strike notch served as the initiating factor in all tests, with variables such as temperature, force, etc., measured for significant correlations. Through these tests, such measures of significance as the nil ductility transition temperature, the nil ductility factor, the factor transition elasticity, the factor transition plasticity were developed. The questions which were asked after the meeting underscored the absorbing interest of those present.

WELDING FUTURE

Buffalo, N. Y.—Robert T. Brown AWS, manager of sales, Metal and Thermit Corp. took a look into the crystal ball and came up with some conjectures concerning the future of welding at the February 28th meeting of the *Niagara Frontier* Section AWS, held at Mann's 300 Club. Those most interested in that future, the 71 members and guests present, were happy with his optimistic views. Welding has increased in ratio to steel tonnage over the years and, with the present and proposed increases in capital expenditure, a future percentage growth can be expected. A lively question session followed the talk.

RESISTANCE WELDING HEAVY STRUCTURES

Lima, Ohio—Forty-six members and guests of the *North Central Ohio* Section enjoyed a dinner and meeting in the Cypress Room of the Clemans Building on Friday, March 1st.

An after dinner feature was the showing of a movie entitled "New Horizons in Aluminum Brazing," courtesy of the Aluminum Co. of America. The movie showed the method being used in the manufacture of aluminum products.

Speaker of the evening was William J. Farrell AWS, chief application engineer of Sciaky Bros., Inc. His topic was "Resistance Welding of Heavy Structures." Mr. Farrell explained the application of resistance welding in fabrication of heavy structures and the tooling required. He also explained how resistance welding of long members reduced distortion as compared to long parts which are are welded.

PUZAK SPEAKS ON IMPACT TESTS

Technical chairman P. Patriarca and guest speaker P. P. Puzak are shown at the March 11th meeting of Northeast Tennessee Section. The significance of impact tests for heat-treated steels was the subject of Mr. Puzak's talk

IMPACT TESTS

Oak Ridge, Tenn.—On March 11th, the *Northeast Tennessee* Section held a dinner meeting at the Elks Club in Oak Ridge, Tennessee. The guest speaker was P. P. Puzak, of the Naval Research Laboratory, Washington, D. C., who spoke on "The Significance of Impact Tests for Heat-Treated Steels."

During the course of the talk, which was accompanied by slides, Mr. Puzak explained many brittle fractures which were a direct result of the use of steels with too high a transition temperature for the service requirements, and the failure of other steels which were notch sensitive. In many cases, other fractures than those resulting in complete failure were stopped by weld beads and did not penetrate into adjacent plates. Mr. Puzak pointed out that notch Charpy tests gave an indication of what the steels could stand under impact, and a series of these tests at various temperatures would give a good indication of the transition temperatures. It would then be up to the engineer to design the equipment and specify the correct steel for the application. The Naval Research Laboratory has developed equipment and facilities for full scale testing of large sections of plate, bar and other shapes so that impact results do not have to be extrapolated from small specimens to large specimens, but can be taken directly. The method is expensive because of the material requirements, although very valuable when large tonnages of plate or forgings are involved.

Some of the slides showing complete ship fractures were quite startling, and the group was impressed with the serious consequences which can result from the use of improper materials.

WELDED-PLATE DESIGN

Olean, N. Y.—Two engineers of the Hammond Iron Works of Warren, Pa. were guests of the *Olean and Bradford* Section at the March 19th meeting held at the Olean House. These were Alex Fino, chief engineer and Harold Mader, welding engineer.

The main speaker, Mr. Fino, chose as his subject "Design for Welded Plate Fabrication," which was illustrated with about 50 slides.

Forty members and guests were present at this very fine meeting.

AUTOMOTIVE WELDING

Philadelphia, Pa.—One hundred members and guests of the *Philadelphia* Section attended a meeting on February 18th and 50 were present for dinner at the Engineer's Club.

Technical speaker was J. F. Randall AWS, of the Ford Motor Co., Detroit. His topic was "High Production Automotive Welding."

Mr. Randall described several unusual welding operations which have been highly mechanized, with a minimum amount of manual effort required on the part of the operator. It was fascinating to listen to Mr. Randall quote "Amos and Andy" figures of production rates for the various installations. While the majority of the audience had little need for such a degree of mechanization in their work, it was gratifying to see the number of visitors who had traveled many miles just to hear Mr. Randall's talk. The interest of the audience was also reflected in the number of questions which arose during the talk and directly following same. In fact, the question and answer period was interrupted so that the film on Applied Automation could be presented. It was with reluctance that Mr. Randall was allowed to leave the speaker's platform.

District Director Don Howard was also present at this meeting, and the Section was well represented.

ARC CUTTING

Pittsburgh, Pa.—Two speakers were scheduled for the March 20th meeting of the *Pittsburgh* Section held in the auditorium of the Mellon Institute of Industrial Research.

BIBBER SPEAKS ON T-1 STEEL

Part of the group at the February 25th meeting of the San Francisco Section who heard Leon C. Bibber discuss the weldability of T-1 Steel

Guest speaker shown with officers of Section: left to right, E. R. Babylon, S. Roberto, L. Robbins, F. Stettner, B. F. Faas, C. Robinson, W. F. Ajello, Mr. Bibber, C. W. Doggett and D. Rowen

The first speaker was Myron D. Stepath AWS, president of Aircair Co., Lancaster, Ohio. His subject was "Compressed-Air Arc Cutting and Gouging." Mr. Stepath discussed this process and its applications, using slides to illustrate his talk.

The second speaker was Paul B. Dickerson AWS, Joining Section, Alcoa Process Development Laboratories, New Kensington, Pa. His topic was "Arc Cutting Aluminum Alloys." Mr. Dickerson covered two recently developed methods of inert-gas arc cutting, including equipment requirements, cutting procedures, cutting speeds for various plate thickness and the quality of cut. He also used slides to illustrate his talk.

IRON-POWDER ELECTRODES

Rochester, N. Y.—The *Rochester* Section had a busy month, with a nominating committee meeting in addition to the regular monthly business meeting.

The monthly business meeting was held at the Liederkranz Club on Monday, March 18th. At this meeting, the technical speaker was Donald B. Howard AWS, supervisor of metallurgy and welding at the General Laboratories, Research and Development Department, American Car and Foundry. Mr. Howard is director of AWS District No. 2.

Mr. Howard, during his nine years with ACF, has devoted much effort to the evaluation of new welding materials and processes and their subsequent application in the railway equipment and ordinance field. Prior to his association with ACF, he was a metallurgist at the American Steel and Wire Division of United States Steel. He spoke on the "Evaluation of Iron-Powder Electrodes," and about 70 members and guests found the talk very enlightening.

CAL POLY STUDENTS HEAR BARNETT

On January 19th the AWS Student Chapter at Cal Poly heard Orville T. Barnett speak on welding processes. Above, left to right, are Jim Miller, chapter vice-chairman; Prof. Richard Wiley of Cal Poly; Mr. Barnett; Ralph Miller and Wayne Marcellin, secretary-treasurer and chairman, respectively, of the Chapter.

AUTOMATION IN WELDING

Saginaw, Mich.—Besides enjoying another fine meal at Chris' High Life Inn, the 65 members and guests of the *Saginaw Valley* Section were privileged to hear J. H. (Hank) Brems of Expert Welder speak on "Weldamation."

Mr. Brems has had wide experience in incorporating associated operations such as material handling, forming, folding, etc., with both the resistance and arc-welding processes.

In a well organized and concise talk, Mr. Brems stressed the point that, while the present trend in welding machine design approaches that of the machine tool, industry in general has been slow referring to welding equipment as a machine tool. The present emphasis on both machine design and quality by the manufacturer indicates that the welding industry is very capable of building machine-tool-type equipment; however, industry in general does not specify, or is limited price-wise, from purchasing this type equipment.

Before the meeting, an excellent film entitled "Insert Welding High-Pressure Vessels for Highly-Corrosive Materials," was shown through the courtesy of the Electric Boat Division of General Dynamics.

CARBIDE

San Antonio, Tex.—The regular monthly dinner meeting of the *San Antonio* Section was held at Youngblood's on Tuesday, February 26th at 6:30 P.M. with 48 members in attendance.

A color film secured from the National Carbide Corporation entitled, "Manufacturing in Process of Carbide" was shown after dinner. This proved to be a most interesting and informative program.

Welding correspondent visits A. O. Smith

gets low-down on industry's most talked-about new development . . . views time-cost studies . . . comes up with revealing answer to question — —

What about C-OMANUAL ?

It's a complete, integrated package for gas-shielded (CO_2) semi-automatic hand gun welding.

Introduced to production early in 1956, C-OMANUAL is A. O. Smith's answer to the need for a fast, economical and easy-to-use semi-automatic welding process. It incorporates a new featherweight hand gun, portable control console and an A. O. Smith power source. The entire compact package requires only a few square feet of space and is perfectly adapted to an extremely wide range of production or special job requirements.

Already proving itself in plants throughout the U. S., C-OMANUAL is the most talked-about, most important welding development since the coated electrode. And the principles of CO_2 shielding have been more than adequately proved by C-OMATIC, the A. O. Smith automatic welding process.

Reporter observes typical C-OMANUAL installations as operator explains ease of hand gun manipulation featuring visible arc and automatic arc length control.

It's EXTREMELY EASY to set up, use and operate... makes changing wire sizes a breeze.

With C-OMANUAL, the welder merely sets the proper current on the rectifier, pushes a start button for power. The hand gun automatically compensates for arc distance variations, and the portable control console is right at hand for fine adjustments. There's no flux to clean, no slag to remove. And the visible arc lets the welder see his work at all times.

WIRE: A. O. Smith has developed wires that will make sound, strong welds on all commercial steels currently in use—rim, semi-killed or killed. The characteristics of the wire include tolerance for the presence of oils, lubricants, scale, foreign material, etc.

The console features easy-to-read, conveniently grouped controls. Large, easy-opening doors swing out for fast, simple wire reel changing. In demonstrations at various welding shows, welders were making highly satisfactory welds the first time they used the C-OMANUAL process.

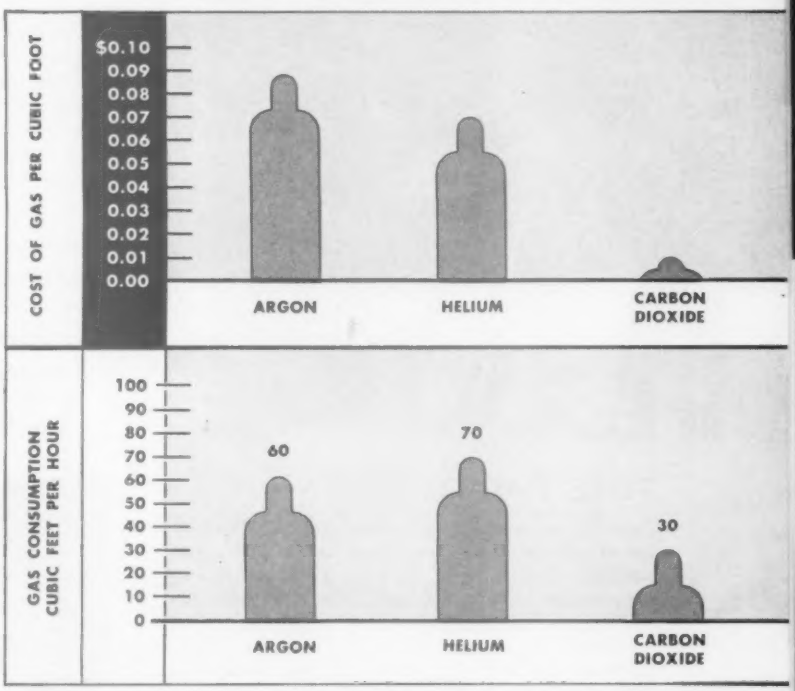
Carbon dioxide is the most efficient, economical of all shielding gases.

Lab tests, confirmed by numerous users, indicate radiographically sound welds with mechanical properties equal to the best produced by coated electrodes or by any other welding process. Tests were conducted on single, double and multi-pass butt welds . . . longitudinal, circumferential, positioned fillets and on plug and 3 o'clock welds. All were completely satisfactory.

And, as you can see in the charts at right, C-OMANUAL saves thousands of dollars annually over other shielding gases.

NOTE: On the following pages CO_2 welding is compared with hand electrodes and semi-automatic submerged arc. The charts above make it apparent that the high costs of Argon and Helium eliminate them from serious consideration for mild steel applications.

The C-OMANUAL wire feed driving mechanism is contained in the console and is easily accessible. The changing of wire reels and unit inspection is extremely simple. 60-lb. coils of any diameter are self-contained in the console. Special provision for economy "pay-off" packs can be made for large users.



Charts show comparative cost per cubic foot and relative consumption rates of Argon, Helium and Carbon Dioxide. Prices are based on standard-size cylinders. For users who'll want to use C-OMANUAL extensively, CO_2 in liquid form can be purchased in bulk storage tanks, converted to gas and piped into the job for less than half a cent per cubic foot.

SEE FOLLOWING PAGES FOR TIME AND COST COMPARISONS

How C-OMANUAL three other

whatever your means of measuring welding costs, C-OMANUAL comes out on top

To spotlight the tremendous advantages offered by C-OMANUAL, A. O. Smith ran tests against submerged-arc (semi-automatic) process and the two types of stick electrodes usually used for jobs of this type. Box at right gives set-up information on tests. Data pertaining to "manual submerged-arc" in all following charts was compiled from manufacturers' operation manuals.

SET-UP DETAILS ON IDENTICAL ¼", 100-FT FILLET WELDS

	E-6013	E-6024	Manual Submerged-Arc	C-OMANUAL
Electrode	1/4"	7/32"	5/64"	1/16" CO-86
Amps*	320	250	350	520/530
Volts	22/23	23/24	32	40/41
Polarity	a-c	a-c	Reverse (+)	Reverse (+)

*Detailed explanation of amp variations involves the lengthy theory of C-OMANUAL's High Current Density method. It suffices here to say amps tabulated are estimated as normal ratings for the various processes on this particular job.

TRAVEL SPEEDS AND METAL DEPOSIT RATES

In addition to inherent speed, C-OMANUAL gives the operator a visible arc. He can fully utilize its high speed and fast metal deposit because he just pulls the trigger, follows the joint until the weld's complete. There's no need for stops to check his progress, no interruption when he moves from pass to pass.

Chart I

	E-6013	E-6024	Manual Submerged-Arc	C-OMANUAL
Travel Speed (ipm)	12.5	18.5	21.4	40.0
Deposit Rate (lbs/hr)	6.65	9.81	11.4	21.0

C-OMANUAL is 84% to 220% faster . . . deposits 87% to 216% more metal per hour than other processes

TIME FACTORS

Four factors combine to make C-OMANUAL the fastest process in its class. First, set-up and current setting are easy. Next, the hand gun automatically compensates for distance variations, eliminates time-wasting trial-and-error as well as false starts. Working with a visible arc, the operator need not stop to check how the weld is progressing. Last, but far from least, there's no slag to chip, no flux.

Chart II

Time (hrs.)	E-6013	E-6024	Manual Submerged-Arc	C-OMANUAL
Arc	1.590	1.080	0.930	0.500
Electrode Change	.075	.066	—	—
Slag Removal	.130	.084	0.120	—
Total	1.795 (1 hr, 40 min)	1.230 (1 hr, 15 min)	1.050 (1 hr, 3 min)	0.500 (30 min)

C-OMANUAL completes 100-ft weld 110% to 259% faster than other processes

stacks up against welding processes

COST FACTORS

The figures in the chart to the right have been compiled on the basis of the tabulations in charts I and II. All cost figures are based on an *exact* (by weight) ¼" fillet 100 ft in length. It's interesting to note that if the "overhead" or burden figure were increased, the advantage in favor of C-OMANUAL would become even more pronounced.

Chart III

Cost	E-6013	E-6024	Manual Submerged-Arc	C-OMANUAL
Labor @ $2.50/hr.	4.49	3.08	2.63	1.25
Overhead @ 150%	6.74	4.62	3.95	1.88
Power @ .01/kwh	.14	.08	.17	.17
Flux	—	—	1.43	—
Gas (CO_2) @ .01/ft3	—	—	—	.15
Electrodes or Wire	2.09	2.86	1.38	3.09
Total	$13.46	$10.64	$9.56	$6.54

RESULT- based on charts I, II and III C-OMANUAL cuts total welding cost per 100 feet by 31% to 51%!

The Wire...

The most popular C-OMANUAL wire is CO-86 — an exclusive A. O. Smith development.

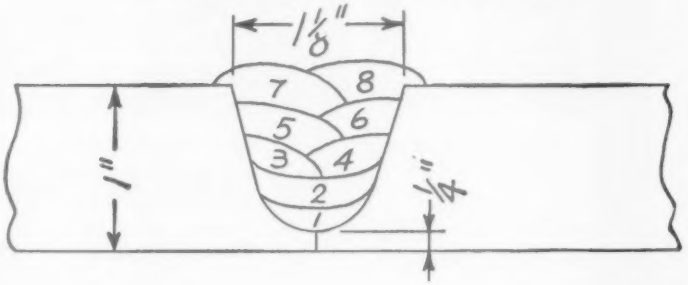
CO-86 produces a weldment with physicals comparable to those of the finest Low Hydrogen electrodes.

It has the ability to weld through oil and rust and can be successfully used on many off-chemistry and hard-to-weld steels. It will tolerate some high sulphur and high carbon steels.

TYPICAL MECHANICAL PROPERTIES (as welded.)

All-weld Metal Test Coupon - 1020 Steel

Beads 1 thru 6 — 36 volts — 395 amps
Beads 7 thru 8 — 38 volts — 390 amps



All Weld-Metal .505 Mechanical Tests

Yield Point (Drop of Beam)	Tensile Str.	Elong.	Red. of Area
57,850	73,300	31.5%	61.8%

If you'd like to know more about C-OMANUAL, get graphic proof how it can greatly improve your present set-up, cut costs, win favor with welders, too, write direct for comprehensive details. Please describe, briefly, the type of work you're currently handling or planning to do. Address inquiries to A. O. SMITH, WELDING PRODUCTS DIVISION.

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to 259% faster than other processes

WELDING PROCESSES

San Luis Obispo, Calif.—On the 19th of January, the Student Chapter at the California State Polytechnic College had the privilege of hearing Orville T. Barnett [AWS], assistant manager of Armour Research Foundation speak on "Which Welding Process and Why." After his presentation, Mr. Barnett discussed the tremendous opportunity in the welding field for young engineers.

T-1 STEEL

Berkeley, Calif.—The *San Francisco* Section, holding its regular meeting at Spengers Fish Grotto, Berkeley, on February 25th, heard Leon C. Bibber [AWS], chief research engineer, Welding, U. S. Steel Co. speak on "The Suitability of T-1 Steel for Pressure Vessel Construction."

Mr. Bibber said that, with the introduction of T-1 steel, quenched and tempered alloy-steel plate had become available to civilian engineers. Explaining that T-1 is complex low-alloy steel, water quenched from 1700° F and tempered at 1200° F to give nominal minimum mechanical values of 105,000 psi ultimate and 90,000 psi yield, he demonstrated by illustration that it nevertheless has the ductility needed for cold forming. A principal advantage of the heat-treated steel, he said, is that it has very low ductile-to-brittle transition temperature even in the water-quenched state. Its weldability, he held, stems from the fact that the heat-affected zone bordering the weld is essentially a quenched structure having a low transition temperature and higher strength than the base metal. When the welds are made with electrodes giving 100% efficiency, there is no loss of strength at the welds and the composite weld structure has ample notch toughness.

The increase in transition temperature normally associated with increasing thickness for pearlitic plate does not become apparent in T-1 steel until thickness greater than 4 in. are reached and this is because it is no longer physically possible to quench the plate to low-carbon martensite.

Movies of the well known Birmingham static and drop tests of full size T-1 steel tanks were shown. These tanks, tested at −50° F, failed with a shear-type, ductile failure under both the impact and burst tests and at membrane stresses in excess of the plate strength.

ALLOY PRESSURE VESSELS

Toledo, Ohio—The March meeting of the *Toledo* Section was held Tuesday, March 19th, at the Maumee River Yacht Club. As usual, the meeting was preceded by dinner which was attended by eighty-four members and guests.

At 8:00 P.M., those present adjourned to the main ballroom for the general meeting and technical session. Walter Schmidt, chairman, welcomed the one hundred and twelve members and guests.

Technical speaker was Perry C. Arnold [AWS], of the Chicago Bridge & Iron Company, who spoke on "Welding of Alloy Pressure Vessels."

Mr. Arnold began his talk by taking his audience on a photographic trip from Chicago to Tokyo, Japan. He then showed a series of slides showing spheres built in Japan, using Japanese laborers and welders, and built of "T-1" steel. The problems encountered with this steel during this construction were discussed, and these problems and their solutions were the basis for Mr. Arnold's technical discussion.

The fabrication of test rigs to duplicate stress distributions as encountered on the job and the evaluation of specimens welded in these jigs at the Chicago Bridge Co. laboratories were discussed. Where definite conclusions could be drawn, these were discussed and evaluated, and unanswered questions on these problems were also mentioned.

Following this very interesting and informative talk, Mr. Arnold presented a short movie showing destruction testing of a series of pressure vessels built of "T-1 Steel" and welded by various techniques and with various high-tensile electrodes. Following the movie, a number of questions were presented from the floor and these were answered very thoroughly by the speaker.

All members and guests who were present appeared to get considerable information from this meeting.

INERT-ARC PROCESSES

Wichita, Kan.—The March 11 meeting of the *Wichita* Section was held at Sidman's South Seas Restaurant. Speaker was C. A. McClean [AWS], of the Air Reduction Sales Co., New York. Mr. McClean talked on the subject "Gas-Shielded Arc Welding and Cutting." He used slides to illustrate the high points of his talk which was informative and was later thoroughly discussed. Mr. McClean passed around, for individual inspection, samples of welds on different metals and specialized assemblies.

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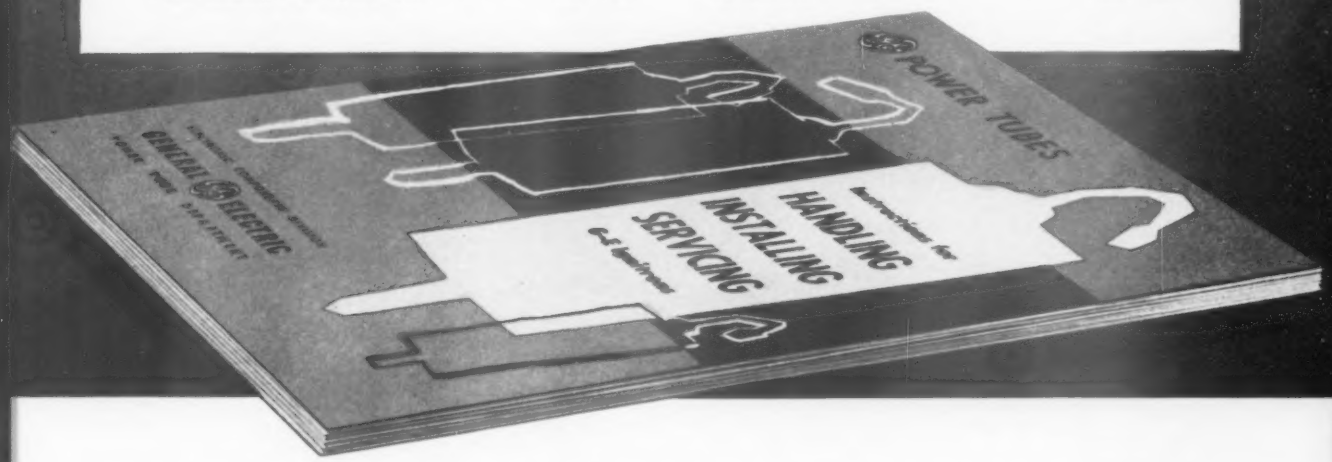
	YES	NO
1. Store ignitrons in a vertical position and in their cartons?	☐	☐
2. Shut off ignitron water supply immediately after operation?	☐	☐
3. Check rectifiers when installing ignitron replacements?	☐	☐
4. Is a slight amount of play desirable in ignitron connections?	☐	☐
5. Measure outlet water temperature to check ignitron temperature?	☐	☐
6. Does a "wet" ignitor show a tube has been operated at too high temperature?	☐	☐
7. Shut off power to thermostat controls immediately after operation?	☐	☐
8. Can nearby electrical fields cause arcs within an ignitron?	☐	☐
9. Can inadequate cooling-water flow cause ignitron failure?	☐	☐
10. Can most premature ignitron failures be prevented by proper maintenance?	☐	☐
11. Will an ignitron with a "wet" ignitor still operate for some time?	☐	☐
12. Does mercury on the anode or glass seal render a tube permanently useless?	☐	☐
13. Should tops of ignitrons on standby be kept slightly above room temperature?	☐	☐
14. Should negative voltage be applied to the ignitor?	☐	☐



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D—Student E—Honorary Member F—Life Member

Total National Membership

Sustaining Members	*139*
Members	*5,948*
Associate Members	*6,313*
Students	*203*
Honorary Members	*8*
Life Members	*15*
Total	*12,626*

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Tuthill, Arthur H. (B)

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Belasco, Rudolph (B)
Durkee, Lawrence G. (B)
Granlund, Ernest A. (B)
Happ, Marvin B. (B)
Kearney, David J. (B)

BRIDGEPORT

Near, Dale B. (C)
Zielinski, Sigmund (B)

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Naka, Anthony T. (B)

CHICAGO

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King, Grenville N. (B)
Martin, Charles V. (B)
Nolen, Robert K. (C)
Schauwecker, Karl F. (B)
Townsend, Edward A. (B)

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Richards, James W. (C)
Wade, Lee S. (B)

CLEVELAND

Hodge, James C. (A)
Jenkins, Henry (B)
Krupienski, Stephen (B)
Lund, Jeffery L. (C)
Netto, Michael J. (B)
Nielsen, C. A. (B)
Pesek, Fred A. (B)
Profughi, V. A. (B)
Rush, Ted W. (B)
Solarz, William W. (B)

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Manning, A. B. (B)

COLUMBUS

Jarrett, James R. (B)

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DAYTON

Buchanan, Robert K. (C)
Williams, Walter (C)

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Gray, George L. (B)
Knowles, Leslie F. (B)
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Misenheimer, Charles V. (B)
Purcell, G. B. (B)
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Sroka, Joseph J. (B)
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Kegg, David C. (C)
May, Jack E. (B)

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Ramirez, Peter B. (D)
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Shoop, Charles William (B)
Yasumura, Jobu (C)

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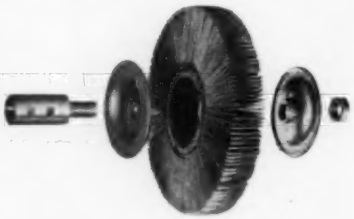

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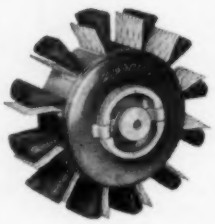

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Brown, David A. (C)
Collins, Fred R. (B)
Gue, Barron J. (C)
Iannucci, Anthony L. (C)
Maga, Alfred J. T. (B)
McCurdy, Carl J. (C)
Pikunas, Walter P. (C)
Swidal, Joseph P. (C)

PORTLAND

Saunders, David T. (C)

PUGET SOUND

Hattrup, John S. (B)
Martin, Thomas J. (B)
Meacham, William Arthur (B)

RICHMOND

Wilson, Roger C. (B)

ROCHESTER

Haslip, L. Robert (C)
Houle, John B. (C)
Wattell, Carl F. (B)

SAGINAW VALLEY

Lutz, Phillip A. (D)

ST. LOUIS

Ebling, Harvey (B)
Jackson, Herman R. (C)
McIntire, Winfred C. (C)
O'Leary, Firman L. (B)
Parker, Gregory P. (B)
Rauls, Frank (B)

SALT LAKE CITY

Wunderlich, J. W. (B)

SAN ANTONIO

Lang, Edward R. (B)
Watson, Willis M. (B)

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Beaton, John L. (B)
Brooks, Charles, Jr. (D)
Clark, Curtis (B)
Gibson, James F. (B)
Holmes, Neal A., Jr. (B)
Moore, Dwight R. (B)
Page, James Dale (C)
Sherman, Dean L. (D)

SANTA CLARA VALLEY

Chaffin, Keith A. (C)
McGarvie, Roderick Gordon (B)
Redmond, Howard J. (C)
Santos, Cesar O. (C)

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Hodges, Dean M. (B)

STARK CENTRAL

Bennett, Sam R. (C)
Horst, Robert V. (B)
King, Robert H. (C)
Miller, Kenneth (C)
Moore, Richard L. (B)

SUSQUEHANNA VALLEY

Luchak, Dorsie (C)

SYRACUSE

Brennan, Bruce A. (C)
Woodruff, C. A. (C)

TOLEDO

Mullen, W. C., Jr. (C)

TRI-CITIES

Byers, Reid S. (C)

TULSA

Mauck, Orville S. (B)

WASHINGTON, D. C.

Kobler, Julian S. (C)
Walbridge, Harry C. (C)

WESTERN MASSACHUSETTS

Warren, Duncan R. (B)

WESTERN MICHIGAN

Caughey, Carl W. (B)
Lincoln, Bela H. (C)

WICHITA

Lucas, Arthur Kenneth (B)

YORK-CENTRAL PA.

Baker, Rodney Lee (C)
Brewer, Albert William (C)
Leatherman, Eugene D. (C)
Steffy, Lester S. (B)
Wills, Edward J. (B)

NOT IN SECTIONS

Branders, Hans Alec (B)
Karlsson, Erik S. (B)
Lavonius, Henrik R. (B)

MEMBERS RECLASSIFIED DURING THE MONTH OF MARCH

BIRMINGHAM

Jones, Bruce M., Jr. (C to B)

CHICAGO

Barkow, A. G. (C to A)

CINCINNATI

Klingeman, William E. (C to A)

HARTFORD

Havens, Relf R. (C to B)

LOS ANGELES

Smolen, Alfred M. (C to B)

LOUISVILLE

Bruno, Charles (C to A)

MILWAUKEE

Furgason, Clyde A. (C to A)

NORTHWESTERN PA.

Danner, George E. (B to A)

PHILADELPHIA

Cass, Boyd E. (C to A)
Dooley, Charles Lewis (C to A)
Gaughan, Michael F. (C to B)

PORTLAND

Amonson, Peter L. (B to A)

PUGET SOUND

Morris, J. B. (C to B)

ROCHESTER

Potter, Samuel (B to A)

SAN FRANCISCO

Chacko, Joseph (D to C)

TOLEDO

Schmidt, Walter F. (C to B)

USS TECHNICAL WELDING DATA

2

How to weld USS "T-1" Steel

USS "T-1" Steel can be welded by any of the following processes:

1. **Shielded metal arc (covered electrodes)**
2. **Submerged arc**
3. **Inert-gas-shielded arc**

The thermal cycle of these processes does not harm the unusual physical properties of this quenched and tempered constructional alloy steel. Other welding processes which subject the steel to prolonged heating, with a resultant slower cooling rate, should not be used with USS "T-1" Steel without first establishing the suitability of the process.

SHIELDED METAL-ARC WELDING. Low-hydrogen electrodes of the E-9015 and E-9016 to the E-12015 and E-12016 classifications should be used to weld USS "T-1" Steel. (Suitable low-hydrogen iron powder electrodes of the same strength range are now available.)

To develop 100% joint efficiency, even with reinforcements removed, electrodes of the E-120 class should be used. Lesser, but often adequate, efficiencies can be obtained with electrodes of lower classification.

If a weldment must be stress-relieved, Nickel-Molybdenum-Vanadium type electrodes must not be used because the heat of stress-relieving, while it does not affect the steel itself, does reduce the toughness of the weld metal.

When welding USS "T-1" Steel to other types of steel, use low-hydrogen electrodes of strengths suitable for the other steel. Remember that weld metals under these conditions develop greater yield and ultimate strengths because admixing of elements from the USS "T-1" Steel enriches their usual chemical compositions.

SUBMERGED-ARC WELDING. Since the currents used in this process are often higher than those used in hand welding, extra care should be taken when welding USS "T-1" Steel to prevent excessive heat input to the base metal. Use multipass welding wherever possible and keep the heat input per inch below that generally used with manual welding.

When you weld USS "T-1" Steel by the submerged-arc process, perform preliminary tests to determine the optimum speed, voltage, amperage, and other welding conditions for the various thicknesses involved before you start welding the finished work. Don't use semi-automatic submerged-arc welding, in which the welding speed is controlled manually, unless you can maintain good control of the speed and, hence, of the heat input.

INERT-GAS-SHIELDED ARC WELDING. Some USS "T-1" Steel weldments have been made by this process with satisfactory results. In these instances, when Nickel-Molybdenum-Vanadium electrodes were used, the weld metal deposited had properties very similar to those obtained with covered electrodes of the Nickel-Molybdenum type.

REMEMBER THIS: In what other alloy plate steel would you find the combination of properties that "T-1" Steel possesses? Here, in just one steel, you get very high yield strength (90,000 psi minimum), extraordinary toughness, great resistance to impact abrasion, and good high temperature strength. These let you reduce the size of highly stressed parts . . . save weight, reduce the amount of welding required, and cut your costs. USS "T-1" Steel is being used in bridges, excavating equipment, pressure vessels, towers . . . in equipment that must take heavy abuse in sub-freezing temperatures . . . in equipment that must withstand heavy stresses and impact abrasion at temperatures as high as 600° F.

WRITE FOR COMPLETE INFORMATION about the application and fabrication of USS "T-1" Steel. United States Steel, Room 5604, 525 William Penn Place, Pittsburgh 30, Pa.

USS "T-1" CONSTRUCTIONAL ALLOY STEEL

"USS" and "T-1" are registered trademarks.

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For copies of articles, write directly to publications in which they appear

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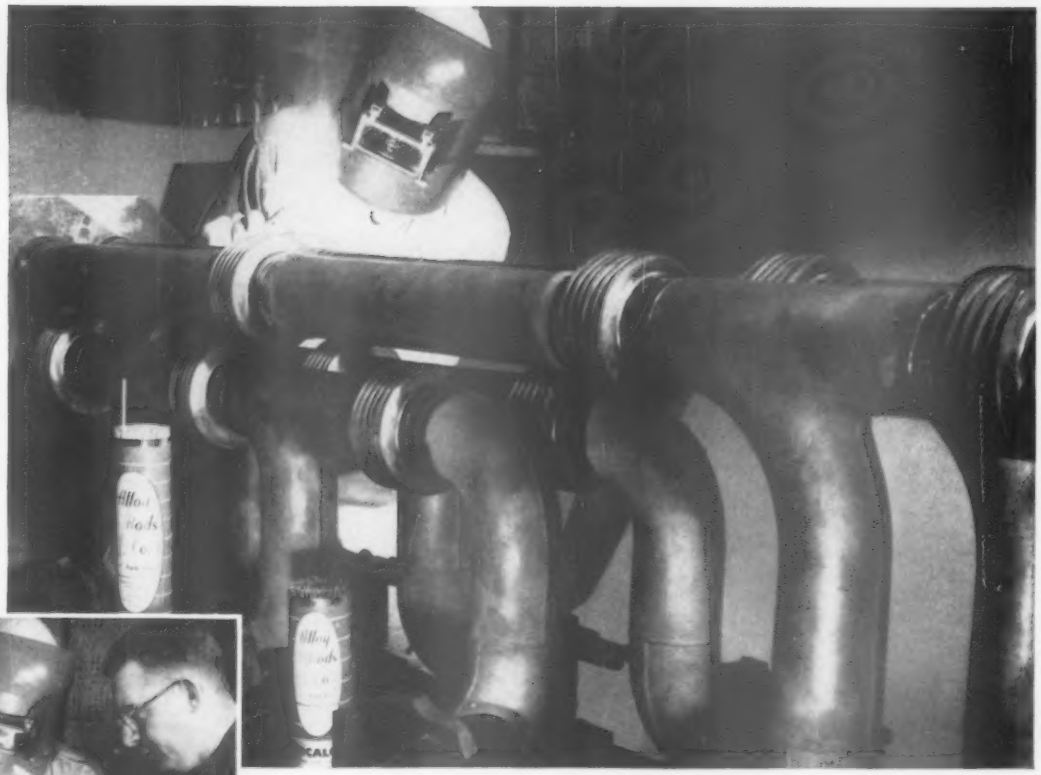

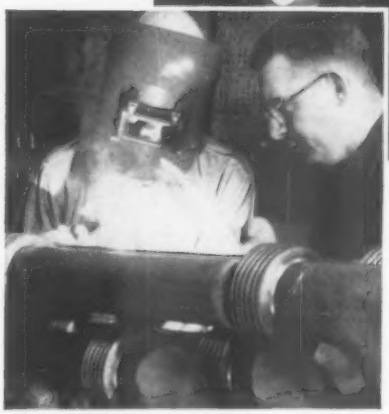

Phil Hoener looks on as the weldor joins a bellows to the type 321 stainless manifold with Arcaloy type 347 electrodes

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Highly corrosive diesel fumes at temperatures up to 1300° F. is the reason why Philip Hoener, Shop Superintendent, specified Arcaloy 347 AC-DC electrodes for the welds in this new stainless steel manifold for diesel engines.

Hanlon & Wilson Company, Pittsburgh, Pa., are the developers and manufacturers of this revolutionary, exceedingly superior manifold design which more than doubles the service cycle of railroad diesel engines.

The key to this development is a series of stainless steel bellows of unique design. Fourteen of these bellows working on a horizontal sleeve arrangement have eliminated failures caused by expansion and contraction, vibration, gas pressures and of course, corrosion.

There are 25 grades of Arcaloy stainless steel electrodes, in lime or AC-DC coatings, that will improve your product . . . provide a better quality weld metal. Write for a copy of bulletin AR-10, the selector guide to superior quality stainless steel weld metal.

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ABSTRACTS OF CURRENT PATENTS

prepared by Vern L. Oldham

Printed Copies of patents may be obtained for 25c from the Commissioner of Patents, Washington, D. C.

2,776,361—Sigma Spot or Tack Welding—Jacob F. M. Essig, Avenel, N. J., assignor to Union Carbide and Carbon Corp., a corporation of New York.

Essig's patent is on spot-welding metal wherein overlapped parts of two metal members are provided and the tip of a fusible metal electrode is bathed in a suitable arc-shielding gas and an arc is initiated between the electrode tip and the side of the work. An electrode is fed mechanically toward the work to fuse the end of the electrode and the adjacent metal of the part so that as the electrode tip is advanced axially into the resulting fused hole, a crater is formed therein which extends into the lower of the overlapped metal parts. Filler metal from the fusible electrode is deposited in the crater and hole so produced to form a weld between the parts and the electrode feed and arc duration are so timed with relation to feed of the electrode that the weld action is stopped before a hole is formed extending completely through the lower part so that the parts will be united with solid weld metal extending from the bottom of the crater in the lower part to the upper surface of the upper part.

2,776,362—Magnetic Force Resistance Welding Machine—Jerome B. Welch, Wauwatosa, Wis., assignor to Cutler-Hammer, Inc., Milwaukee, Wis., a corporation of Delaware.

This patent upon a magnetic force welding machine relates to apparatus including a pressure actuated device, a movable electrode and a connecting rod providing a driving connection between the device and the electrode. A magnet core is symmetrically disposed about the connecting rod and includes a pair of pole portions positioned on opposite sides of the connecting rod. An elongated armature is also present and has end portions for attraction by the pole portions. Other means provide rotary adjustment of the armature with respect to the magnet core so that the members can be placed out of alignment with each other to vary the magnetic gap therebetween. Yet other means in the apparatus limit the armature to movement in a single plane and provide a further adjustment for control of the magnetic force transmitted to the movable electrode.

2,776,363—Arc Welding Process and Apparatus for Use Therein—Harold Spencer Payne, Cleveland, Ohio, assignor to the Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

Payne's arc-welding apparatus is of the type wherein a metallic electrode, such as a wire, is fed continuously to the work and a relatively stationary wire-feeding mechanism and a remotely located portable welding head are provided. A welding tool and a flux hopper are mounted on a work-engaging carriage and are adapted to oscillate with relation to movement of the carriage on the work. This welding tool and hopper are adapted to be used when detached from the carriage for use in manual welding operations, as desired.

2,776,474—Method of Continuously Producing Welded Pipe—Hans Melcher, Mulheim an der Ruhr, Germany, assignor to Friedrich Kocks, G.m.b.H., Düsseldorf, Germany.

This method is for continuously producing welded pipe from a continuous flat length of steel. First the steel length is cold formed into a split pipe and electrical induction heating action is applied to bring the split edges up to a temperature of about 1300° C which is below the welding temperature for the steel. Thereafter an oxygen containing gas is blown against the edges so that their temperatures are raised to about 1450 to 1650° C and immediately thereafter these localized heated edges are pressure welded together to form continuous lengths of pipe seamed at these localized heated edges.

2,777,046—Joining Ends of Wires—Alfred Vang, Carmel, Calif.

Vang's patent is for welding wire ends and includes the steps of aligning the end portions of the wire which have substantially flat end surfaces thereon. The end surfaces are lightly engaged with each other and high frequency current is applied to such end portions for heating oxide thereon by a dielectric heating action. Additional force is applied to the wire portions to force the end surfaces thereof together when heated by the dielectric heating action.

2,777,047—Power Supply for Multiple Welding Units—Charles H. Stevens, Jr., Cornwall Bridge, Conn.

This patent relates to d-c welding action wherein a magnetic amplifier having a primary winding and three control windings is provided. A rectifier is coupled to the primary winding, whereas a plurality of individually operable welding units are connected through the rectifier to one of the control windings. Means connect another of the control windings for receiving a portion of the output voltage, and a third of the control windings is connected to receive a portion of the supply voltage.

2,777,048—Clamping Device for Butt-Welding of Pipes—Friedrich Kocks, Wermelskirchen, Germany.

The patented special clamping device includes a set of clamping members for introduction into each of a pair of pipes and a common rod on which such clamping members are positioned. One of these clamping members is fixedly secured on the rod and the other is axially slidable thereon. Hydraulic cylinders are provided for cooperation with the clamping members and rod to change the relative distance between the clamping members to move them into and out of pipe clamping positions. Means outside the pipes are provided for heating the pipe ends to welding temperatures when in abutting positions.

2,777,129—Face Shield for Welders—Arthur P. Hummel, La Mesa, Calif.

This patented welder's face shield includes a mask having a pair of horizontally spaced openings therein and a pair of goggles are attached to the mask and include a pair of eye cups extending from the rear of the mask forwardly through an opening in the mask. Protective lens are mounted in these eye cups, and means are provided for clamping the shield to the face of the wearer.

2,777,685—Cutting Torch Guide—Glenn L. Colson, Lawrence, Kan.

Colson's patent is on a burner tip guide and it includes a rolling disk having a hub with a stationary disk journaled on such hub. A burner tip support is adjustably mounted on the stationary disk and stabilizing wheels are provided for the rolling disk and are disposed at one side thereof. Other special means are provided for securing a burner tip to the support provided therefor on the stationary disk.

2,777,928—Arc Welding Method and Means—Arthur A. Bernard, Chicago, Ill., assignor to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

Bernard's new method relates to arc welding wherein a fusible metal electrode is fed toward a base metal through a metallic nozzle and gas confining and distributing means so as to maintain an arc between the electrode and base metal with an arc-generated gaseous envelope therearound. A shielding gas is continuously discharged from the end of the nozzle to maintain an unbroken envelope of shielding gas around the region of the arc-generated gas to exclude atmospheric air from contact with the arc. A coolant is circulated through the metallic gas confining and distributing means to extract heat therefrom.

Plant, Research Laboratories and World Headquarters

BETTER FASTER

Low Temperature EUTECTIC WELDING ALLOYS

STRONGER WELDS

EUTECTIC Welding News

PUBLISHED BY EUTECTIC WELDING ALLOYS CORPORATION, 40-40 172 STREET, FLUSHING 58, NEW YORK, N. Y.

XYRON 2-25 REPAIRS RR DIESEL ENGINE SAVES $10,800, WEEKS OF DOWNTIME

A large break in the first cylinder of a 600 horsepower diesel engine almost resulted in the loss of $10,800 by a Midwestern railroad. Attempts to repair the engine with conventional high heat welding materials failed because the block was thoroughly dirt and oil soaked and its tremendous size made pre-heating impossible.

Fig. 1

The railroad's maintenance foreman was ready to recommend scrapping the engine when Eutectic's District Engineer suggested welding with patented Xyron 2-25, "Eutectic's" newest and most advanced electrode for all types of grey and alloyed cast iron. Xyron 2-25 is usable fast and cold and is the first non-cracking, porosity free, all position electrode for cast iron.

Fig.2

Repair was begun by veeing out all broken surfaces with Eutec-ChamferTrode, high speed gouging electrode for all metals. (Fig. 1) Gouging with ChamferTrode provided a good surface for deposits of Xyron 2-25 and burnt out many of the impurities in the casting. After the broken parts were reassembled on the engine block, Xyron 2-25 was used to tack weld. (Fig. 2).

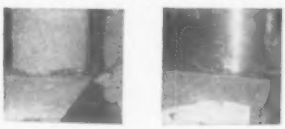
Welding machine was set at 100 amps, DC reversed. The weldor then used a stringer technique with short arc to deposit 2" passes of Xyron 2-25. Peening after each pass relieved stress and slag was easily removed.

Final results were excellent. Xyron 2-25 produced dense, smooth, porosity free deposits at lowest amperages. (Fig. 3) Fast repair with Xyron 2-25 saved railroad $10,800 replacement cost and avoided weeks of downtime. *(A-71)*

HIGHEST STRENGTH JOINTS WITH EUTECTRODE 201

Welded with patented EutecTrode 2101, the aluminum tine joints on this cement block unloader are up to three times stronger than joints of conventional aluminum electrodes. Loads of close to a ton cause the tines to dip as much as eight inches without cracking. EutecTrode 2101 quickly fabricated the block unloader, produced smooth solid deposits with good color match and high resistance to corrosion. The first aluminum electrode with an extruded flux coating, EutecTrode 2101 does not spatter or fume, produces a quiet arc at lowest amperages. EutecTrode 2101 outperforms all conventional aluminum electrodes. *(A-72)*

EUTECTRODE 680 AC-DC AVERTS 10 WEEK STOPPAGE



A Tennessee stamping plant faced an 8-10 week production stoppage because of a cracked shaft on a 340 ton press. Replacement was estimated at $15,000. But downtime was averted and replacement cost saved by using EutecTrode 680 AC-DC and Eutec-ChamferTrode to repair the shaft at a cost of only $37 in materials. Eutec-ChamferTrode, high speed gouging electrode, was first used to vee out the crack, which extended 6" through the 12" shaft. EutecTrode 680, patented high tensile electrode for very high alloy and carbon steels, was then applied. Eutec-Trode 680 welds were applied at lowest amperages. *(A-73)*

In answering industry's requests for technical data, Eutectic's research and engineering staffs help industry save thousands of dollars each year. Your questions, like these below, will be answered without obligation by Eutectic's Technical Information Service.

Q. My company's welding manual makes reference to the use of solder in the repair of lamp socket contacts. EutecRod 157 with Eutector Flux 157 was recommended to us for this application. Will you advise? We would like to incorporate this information in our manual for future use. The fact that this soldering is performed by unskilled personnel should be considered.

A. EutecRod 157 is considered an ideal recommendation. Since this alloy has an extremely narrow plastic range, rapid solidification takes place, assuring a good build-up. It is therefore easier to handle by the unskilled. Deposits are harder and have higher electrical conductivity than conventional solders. This means greater resistances to pitting and general wear. Since the alloy has a higher solidus temperature, the possibility of plasticizing the build-up if accidental arcing occurs is virtually eliminated. Contacts also will remain bright and clean since EutecRod 157 does not contain lead or other elements than darken with age. Melting point is approximately 430° F. Electrical conductivity is 18 percent.

Q. What is the electrical resistance of EutecRods 180, 800, and 1804?

A. Electrical resistivity of all three is almost identical in that values of 23/24 microhms per cubic centimeter are obtained on all tests.

Eutectic Welding Alloys Corporation
40-40 172nd Street, Flushing 58, N.Y.

Gentlemen:

I would like further free information on the following:

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☐ Free 170 page pocket Welding Data Book.

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NEWS of The Industry

Technical Writers' Institute to Be Held at RPI

The fifth annual Technical Writers' Institute will be held at Rensselaer Polytechnic Institute, Troy, N. Y., beginning Monday, June 10th, and running through Friday, June 14th. Planned throughout as an aid to the technical writing profession in industry, the general program will be in charge of Jay R. Gould, director.

In the past four years 300 representatives of 150 national and international companies have attended the Writers' Institute. It is designed for those who supervise technical writing in business, industry and the professions. It also has had a carry-over effect in that a number of companies have based report writing courses on the Technical Writers' Institute curriculum and have called on a number of the regular staff of the Institute for consultation and counseling.

The over-all workshop includes sessions on manuals and instruction books, reports, technical promotion, training programs, industrial films, and graphic and illustrative aids. Laboratory writing sessions put into practice the more general principles learned through lectures and discussion.

A special group of lecturers, in addition to the Rensselaer staff, will demonstrate outstanding accomplishments in technical writing.

Additional information on the next session of the Institute can be obtained by writing Jay R. Gould, Director, Technical Writers' Institute, Rensselaer Polytechnic Institute, Troy, N. Y.

Airco to Build Plant in Boston Area

Air Reduction Sales Co., a division of Air Reduction Co., Inc., will build a multi-million dollar air liquefaction plant for the production of liquid oxygen, nitrogen and argon at Acton, Mass., near Boston, it has been revealed by John A. Hill president of the corporation.

The investment in this new plant, to be started late this Spring, and in related distribution facilities, will be in excess of $9,000,000.

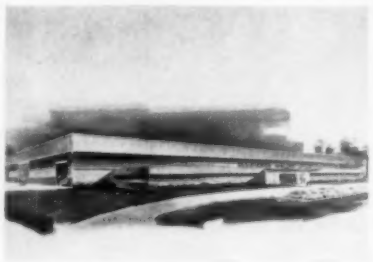
The new Air Reduction facility, which is scheduled for completion during the summer of 1958, is designed to produce 75 tons of liquefied gases per day. Current facilities at the Acton site, where Air Reduction already maintains extensive operations, include an acetylene plant, an electrolytic plant for the production of hydrogen and oxygen, and a sub-station for the re-distribution of liquid oxygen and nitrogen produced by the Air Reduction Sales Co. at its air liquefaction plant at Riverton, N. J. The new facility at Acton will replace the existing distribution sub-station.

Gasflux Appoints Conway

The Gasflux Co., Elyria, Ohio, announces the appointment of Eugene H. Conway as vice-president and manager. He will be responsible for developing and maintaining adequate service in the expanding field of application of the Gasflux process of brazing.

Resistance Welder Building New Plant

Architectural rendering shows new manufacturing plant now under construction by Resistance Welder Corp. in Bay City, Mich., and new general



offices and engineering building which are to be added in the future.

The new plant is scheduled for completion in May 1957 and will provide an additional 40,000 sq ft of manufacturing area. The center bay will provide for the increasing need for large areas required for assembly and tryout of automated resistance welding and allied equipments often extending several hundred feet in length.

General offices and manufacturing facilities will remain at present locations until the new facilities are completed.

Progressive Welder Announces Executive Changes

John D. Gordon, vice-president and general manager of Progressive Welder Sales Co., 3070 East Outer Drive, Detroit 34, Mich. has announced three new executive appointments within the organization.

Irving L. Pond has become sales manager of the Frostrode Div., replacing L. F. Van Nortwick. Mr. Van Nortwick has been named general sales manager of Progressive Welder Sales Co. He replaces George W. Enk, who is joining Progressive's field organization to concentrate on one of the company's major accounts.

Lincoln Adds to District Office Staffs

Barron J. Gue and David M. Thorsen have joined The Lincoln Electric Co.'s district offices at Pittsburgh, Pa., and Union, N. J., respectively. In Pittsburgh, Mr. Gue will be near his native home of Brownsville, Pa., where he

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1958 Spring Meeting and Welding Show:

April 14–18, Statler Hotel, St. Louis, Mo.

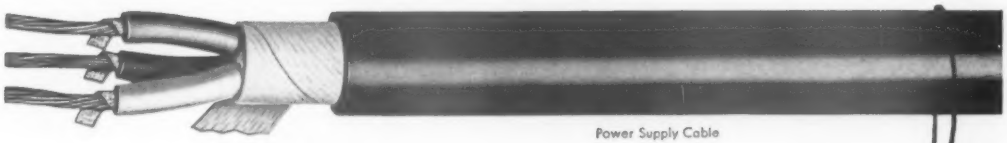
NWSA

May 13–16, 1957. Thirteenth Annual Convention, Hotel Mayflower, Washington, D. C.

ASM

Nov. 4–8, 1957. Thirty-ninth National Metal Exposition & Congress, concurrently with Second World Metallurgical Congress, International Amphitheatre, Chicago, Ill.

If it's worth engineers' time...



Power Supply Cable

...it's worth engineered cable

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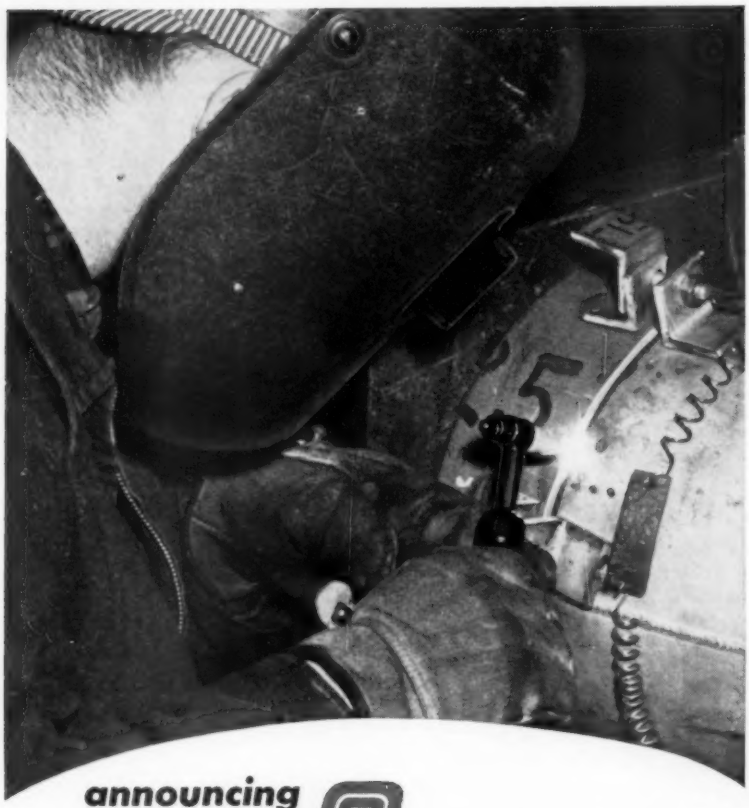
WIREMAKER FOR INDUSTRY
SINCE 1902
CHICAGO

4-W

Magnet Wire • Lead and Fixture Wire • Power Supply Cords, Cord Sets and Portable Cord • Aircraft Wires
Welding Cable • Electrical Household Cords • Electronic Wires • Automotive Wire and Cable

See us at Booth #8 at the National Welding Supply Association Convention in Washington, D. C.

NEW PROCESS
assures improved pipe welds



announcing the ARCOS

EB* WELD INSERT

To meet modern requirements for better pipe welds where high temperature, high pressure, and corrosive conditions exist, Arcos now offers the Consumable Weld Insert. Used for making the root pass, the EB Insert assures sound crevice free welds with smooth uniform inside contours. Saves money and time in fabrication . . . minimizes turbulence, and promotes trouble free service. Write for details. ARCOS CORPORATION, 1500 S. 50th St., Philadelphia 43, Pa.

*trademark of General Dynamics Corporation

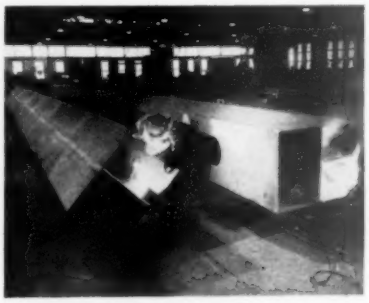
worked for The Pennsylvania Railroad and the Postal Department. He also spent two years with the United States Air Force. Mr. Gue was in Lincoln's training program in Cleveland for 18 months before moving to Pittsburgh.

Mr. Thorsen is originally from Chicago. He graduated from Cornell University in 1950 with a degree in Civil Engineering and from Northwestern in 1951 with a master's degree in Business Administration. A salesman for Acme Steel in Chicago before he joined Lincoln in 1955, Mr. Thorsen moves to Union from the Cleveland District Office.

Welded High-Strength Steel Features New Bridge

Bridge members of "T-1" high-yield-strength steel, now being fabricated at United States Steel Corp.'s American Bridge Division plants in Ambridge and Gary, Ind., will save about $800,000 in material costs for the construction of the new Carquinez Straits Bridge in San Francisco.

The saving is due to the high yield strength of the "T-1" steel, which can be welded and which is capable of resisting stress of 90,000 lb per sq in.—or nearly triple that of structural carbon steel. Over 2900 tons of this material will be used in weldments forming various truss members and gusset plates going into the $20 million bridge. Altogether, American Bridge is fabricating and will erect some 15,000 tons of structural steel on the project.



First steel for San Francisco's new Carquinez Straits Bridge is taking shape at the Ambridge plant of U. S. Steel's American Bridge Division. The $20 million bridge is expected to be completed late in 1958.

The new bridge, which will carry four lanes of eastbound traffic, will parallel the old Carquinez Bridge built by American Bridge 30 years ago, and will match it in span length and general appearance. The structure will provide two 1100-ft-long main spans, two 500-ft-long side spans, and a 150-ft-long mid-crossing tower to carry one-way traffic eastbound of U. S. Route 40.

It is expected that the steelwork for the new bridge will be completed late in 1958.

Motion Picture on Joining of Metals

A new film "Modern Methods For Joining Metals," shows a variety of welding processes and applications, and is treated in a generally non-technical manner, which makes it both interesting and informative. Filmed at leading metal-fabricating companies, and Linde's laboratories, this 20-minute sound and color motion picture illustrates the importance of the welding engineer in industry. It also shows the many factors involved in electric welding, and how research, development and engineering serve to provide increasingly better methods and equipment.

Arrangements to see this picture can be made by contacting the nearest Linde office, or writing to Linde Air Products Co., a Division of Union Carbide and Carbon Corp., 30 East 42nd Street, New York 17, N. Y.

New Eutectic Plant Opened in England

Dedication ceremonies officially marked the opening of a new Eutectic "Low Temperature Welding Alloys" manufacturing plant and service center in

North Feltham, England, on January 15.

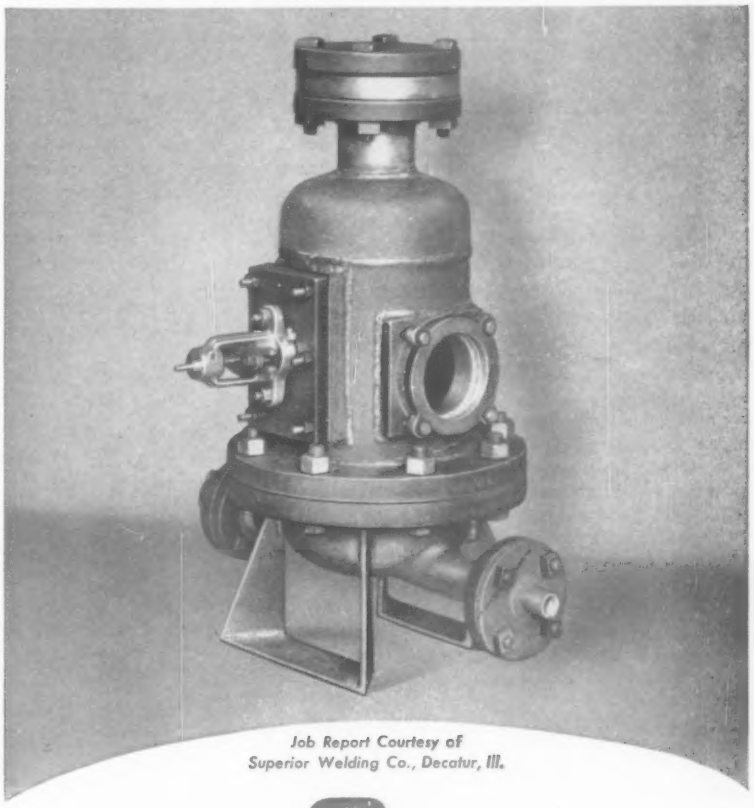
Rene D. Wasserman, chairman of the board of the British firm and president of the Eutectic Welding Alloys Corp. of Flushing, N. Y., pointed out, as principal speaker, that this plant marked the sixth new manufacturing facility opened by Eutectic and its affiliated companies in the last ten years.

Construction of the plant was started early in 1956.

DESIGN PAPERS

Papers dealing with the progress of welding in the fields of *structural design* and *machine design* are solicited for the 1958 AWS National Spring Meeting in St. Louis, Mo. For proper consideration, manuscripts or 500-word abstracts, must reach AWS Headquarters prior to August 15, 1957

For MORE DEPENDABLE Results When Welding Stainless and Dissimilar Metals



Job Report Courtesy of Superior Welding Co., Decatur, Ill.

WELD WITH ARCOS

STAINLESS ELECTRODES

This sight flow box is used to check the condition and flow of process chemicals. To assure sound weldments when joining the carbon steel flanges (stainless faced) to the type 316 stainless unit, Arcos 25-20 Mo Electrodes were used. Because of the analysis and uniform ductility of this weld metal, it readily compensated for the unequal rates of contraction of the dissimilar metals. Arcos KMo Electrodes were used to complete the application. Whatever your job, your Arcos representative will have the answer with the right product and know-how. ARCOS CORPORATION, 1500 S. 50th St., Philadelphia 43, Pa.

INTERNATIONAL WELDING NEWS

Welding Research in the Soviet Union

Translation from the German by Rudolph O. Seitz

(*Continued from April 1957 issue, p. 430*)

Research Management

1. Coordination of Welding Research. Since welding research is being carried on at a number of different institutes, the purposeful coordination of the various research programs constitutes an important problem which has been solved in the following manner.

A central office for the coordination of all the welding research projects in the Soviet Union has been created at Moscow. This office is administered by the Academy of Science of the USSR, and the members of the coordination commission are outstanding welding scientists and engineers. Among these, the best-known are Professor Rykalin and Nikolayev.

All research proposals related to welding must be submitted to the coordination office. After a thorough check, the office makes recommendations. Depending upon the circumstances, some proposals may be rejected, for example, to avoid duplication, others may be reduced in scope, or they may be expanded by supplementary proposals. The purpose of this screening process is to avoid duplication and repetition of research work.

2. Research Plans. In the Soviet Union, as in most other countries, welding research planning is done on a yearly basis, but, in addition, there is also some long range planning which is tied in with the over-all five-year plans of economic development.

3. Project Planning. At every institute, there is a scientific council whose task it is to work out both the annual research programs and the long range plans. Not only the programs of the institutes maintained by the industrial ministries, but also those of the institutes of the Academy of Science and of the technical colleges are thoroughly discussed with representatives of the industrial ministries before the final decisions are made. Six months before the beginning of the next plan year the research institutes submit brief descriptions of their research proposals to the industry and to the respective technical departments of the ministries. These proposals are not secret, but are freely discussed. Suggestions and comments are forwarded to the scientific council of the institutes and are given due consideration in the final formulation of the programs. If there is a difference of opinion, the institute has the prerogative of overriding the recommendations offered by the industry. The plans are also subject to the approval of the central coordination office at Moscow, and the required funds must be authorized by the sponsor.

4. Operating Control. At the beginning of the year, the various projects are discussed by the scientific council of the institute and a rough outline of how a given problem is to be solved is worked out. In the course of the proj-

Rudolph O. Seitz is affiliated with the Air Reduction Laboratories, Murray Hill, N. J., as information specialist.

ect there are periodic discussions and every institute issues short reports to the industry about work in progress.

5. Research and Application. When a research assignment has been completed, great stress is laid on applying the results in practice. In Russia, the term "research" applies not only to the investigation of fundamental problems, but more so to research and development aimed at practically useful results. The German delegation noted with particular interest that even the members of strictly scientific institutes like those belonging to the academies and colleges personally introduce new welding processes and equipment into specially selected plants (model plants) and supervise the further development until all the difficulties are ironed out. To this end, the institutes are very liberal in supplying auxiliary data and equipment, and the scientist in charge of the project has the satisfaction of seeing it through to successful completion.

When a new process or piece of equipment has proved itself in one plant, the general introduction into other plants of the same industry is left to the respective ministries or to the plants themselves. Only when major difficulties arise are the institutes called upon for assistance. In order not to disrupt regular research activity, special groups of experts have been created to do this kind of trouble-shooting.

6. Group Research. Since welding research constitutes in most institutes only a subordinate activity, it is understandable that very often the emphasis is not on welding for welding's sake. The projects usually deal with various production problems in which welding may play a vital part. For this reason, complex groups are formed which consist of specialists in the different fields of science and engineering which have a bearing on the particular project. The head of such a team reports directly to the director of the institute. Frequently, outsiders, i.e., nonmembers of the institute, are recruited. After completion of such a project the team is disbanded.

7. Organization of the Institutes. As a rule, the institutes are organized along the same lines. Welding research is carried on by the various teams within the welding departments, and the effort of the teams is concentrated on a single special field. Each institute has a shop for making model equipment, instruments, etc., and some institutes have larger shop facilities (pilot plants) for producing prototypes for field testing.

8. Evaluation of Research Assignments. At the completion of a research assignment there is an open discussion of the evaluation of the results obtained. Representatives of industry frequently participate in these discussions and it is said that quite often there is sharp criticism and demands for revision. An annual project is concluded with a final report to the sponsor.

9. Financing of Research Assignments. The research assignments are financed either from a research and engineering fund or by so-called commercial contracts with the respective industry. These contracts are a very effective tie between research institute and production plant. The institutes select plants suitable for introducing new methods, processes and equipment and the relationship is formalized by contracts which usually run for one or five years. Every large plant makes budget provisions for the introduction of new methods, etc., and these funds are made available for financing the research contracts. There are also more comprehensive contracts between the academy institutes and whole administrative sections of the ministries. The plants are very anxious to conclude such contracts with the leading institutes, but their number is limited. The main function of these commercial contracts is not merely financial, but they form a basis for the fruitful cooperation between plant and institute, and offer the institutes the opportunity of becoming thoroughly familiar with the needs of the industry, and to adjust their research and development work accordingly.

Welder, by Westinghouse

HIGH FREQUENCY! A-C or D-C! ALL BY REMOTE CONTROL! — FAST!

This Custom Silver "W" *now delivers* —in *one* machine—*all eleven* aids to better, faster, easier welding, that recently were asked for by 2744 welding operators themselves!

You get straight AC welding at its finest. AC welding with high frequency automatically maintained — *ideal* for gas shielding! Or, high frequency utilized only at arc start. Moreover, your high frequency is varied in intensity, as you need it! All with *instantaneous* remote control!

You get DC welding with *full 375 amperes!*—assuring use of *bigger* electrodes! Still you have *immediate, constant* control of high frequency, as desired, for DC gas-shielded welding on the *lightest* work! And all by simple, exacting, remote control that *eliminates craters!*

Then, the Custom Silver "W" also gives you quick polarity selection—built-in, automatic water and gas controls (that clear the line both before and after use)—even an automatic timer for spot welding!

Yet above all this, the Custom Silver "W" incorporates the *easiest settings ever*, with the widest current range overlap in the industry! *Positive* instantaneous arc start, from the Westinghouse pre-energized reactor! And *utmost arc stability known!*—from the Westinghouse, exclusive smoothing reactor—and now from Westinghouse SILICON Rectifiers!

SILICON Rectifier Diodes 98% Efficient!

Hermetically sealed! Ageless! Unparalleled capacity! Give *unprecedented* arc stability, *absolute* depth of penetration desired, *lowest cost* welding now known! *Predicted soon to be copied throughout the entire industry!* J-22087-A

Accept complete information, help, from your local Westinghouse Welding Distributor!

PERSONNEL

Cobb Joins Allied Welder

Wilbur H. "Bill" Cobb has joined the staff of Allied Welder Corp., Dearborn, Mich., according to an announcement by W. R. Plummer, president.

Mr. Cobb has been with Progressive Welder Co. of Detroit for the last 20 years. His most recent activity has been in sales engineering.

Wilbur H. Cobb

At Allied Welder he will serve as liason between engineering and sales departments.

Mr. Cobb is a member of the AMERICAN WELDING SOCIETY.

Caughey Made Chief Metallurgist

The M. W. Kellogg Co., New York, a subsidiary of Pullman Inc., announces the appointment of Robert H. Caughey as chief metallurgist.

Mr. Caughey joined the company in 1946 as assistant chief metallurgist, and has been closely connected with the development of the stainless steels for high-pressure and temperature power piping. He succeeds Harry S. Blumberg in his new position, the latter retiring to become a metallurgical consultant. Mr. Blumberg is a member of the AMERICAN WELDING SOCIETY.

(Left to right) R. H, Caughey, W. McKee and H. S. Blumberg

Buechler Joins Tube Turns

Clarence Matthews Buechler has joined the Sales Development Department of Tube Turns, Louisville, Ky. The announcement was made by John G. Seiller, president of the company.

Buechler was born in Louisville. He obtained his A.B. degree in chemistry at Bellermine College and his M.B.A. degree in business and marketing at the University of Chicago. He is a member of Alpha Delta Phi and the American Marketing Association.

Tube Turns, a division of National Cylinder Gas Co., Chicago, manufactures welding fittings and flanges for industrial piping systems.

Schneller and Buerkel Promoted by A. O. Smith

A. R. Schneller has been named sales manager of welding products and accessories for the Welding Products Division of the A. O. Smith Corp. The announcement was made by R. W. Raney, division general sales manager, to whom he will report.

Mr. Schneller's previous post as eastern regional sales manager for welding products has been taken over by D. H. Buerkel, who formerly was sales representative in the Philadelphia area.

The Messrs Schneller, Raney and Buerkel are members of the AMERICAN WELDING SOCIETY.

Dorr and Mazzaferro Promoted

F. J. Purdy, sales manager, Welding Department, Westinghouse Electric Corp., announces the appointment of P. E. Dorr to the position of manager of brazing and purchased resold products, Welding Department, effective Feb. 15, 1957.

In this capacity Mr. Dorr will be responsible for the sale of the above products and will be located at Buffalo.

Mr. Purdy also announces the appointment of J. J. Mazzaferro to the position of northeastern regional manager of welding sales, effective Mar. 1, 1957.

Mr. Mazzaferro will be responsible for the direction of sales activities of all welding products in the northeastern region and will be located in the Regional Headquarters, 40 Wall Street, New York City.

The Messrs. Purdy, Dorr and Mazzaferro are members of the AMERICAN WELDING SOCIETY.

Russell Elected Vice-President By Beaird Co.

C. E. Russell has been elevated from works manager to vice-president in charge of manufacturing at The J. B. Beaird Co., Inc., Shreveport, manufacturer of heavy steel products, J. Pat Beaird, president, has announced.

The election of Mr. Russell is the first executive promotion since the merger of the Beaird Co. and American Machine & Foundry Co. on Dec. 26, 1956, Mr. Beaird said.

C. E. Russell

His present promotion marks the third advance for Mr. Russell since he became associated with Beaird on June 29, 1953. First assigned as manager of the machining division, Mr. Russell moved up to assistant works manager on June 29, 1954, then advanced to works manager on Feb. 16, 1955.

As vice-president in charge of manufacturing, Mr. Russell will exercise general supervision of production at Beaird's new plant in Clinton, Iowa, scheduled to begin operations this Spring, as well as the Shreveport plant with its complete production lines for the manufacture of packaged compressor plants, LP-gas and anhydrous ammonia storage equipment, piling for offshore drilling platforms, air receivers

How a sand and gravel plant
SAVES UP TO $162 PER WEEK

Amsco® Semi-automatic S/A-53 Tube Rod... used in place of a competitive semi-automatic rod, is saving a large sand and gravel operator up to $162 per week on roll crusher hardfacing. And this is done with no loss of service life... no increase in welding time or rod consumption.

These roll crushers handle 3000 tons of gravel per week, work 10 days between hardfacings. Replacement rolls are hardfaced daily, using about 50 lbs. of rod.

You can make comparable savings by using Amsco S/A-53 Tube Rod in severe impact-abrasion service. S/A-53 is designed especially for use with Amsco MF Semi-automatic Welders, but other machines may be easily adapted to accommodate its $^3/_{32}$" diameter.

S/A-53 is a prehardened, pre-lubricated, high-chromium alloy rod... easy to weld on carbon or manganese steel. Deposits from 5 to 15 lbs./hr. according to current settings. Deposit hardness averages 425 to 475 Brinell.

Any Amsco Distributor will give you a chance to try S/A-53 in an Amsco MF Semi-automatic Welder. Why not take him up on it and test the savings yourself?

Write for Bulletin 656, describing S/A-53 and the complete Amsco "wear-fighter" welding line in detail. Address: Amsco Welding Products Department, Chicago Heights, Ill.

Amsco Welding Products distributed in Canada by Canadian Liquid Air Co., Ltd.

AMERICAN Brake Shoe COMPANY

AMSCO

American Manganese Steel Division • Chicago Heights, Ill.

OTHER PLANTS IN: DENVER, LOS ANGELES, NEW CASTLE, DEL., OAKLAND, CAL., ST. LOUIS, JOLIETTE, QUEBEC

THERMO Spiral
—the ONLY Tip Cleaners that GUARANTEE These OUTSTANDING Advantages

- Accumulated carbon and slag removed without scratching or enlarging orifice.
- Left-hand spiral ridges clean and burnish old tips to new tip efficiency.
- Have no breakage points caused by grooves running horizontally.
- It's the ONLY Tip Cleaner with uniformly rounded cleaning ridges.
- Locked in compact case to prevent damage. Standard set of 12 cleans 27 drill sizes.
- Send for a FREE THERMO Spiral Tip Cleaner TODAY and prove to yourself it can't be broken in normal use.

All Progressive Welding Supply Dealers stock THERMO Tip Cleaners

THERMACOTE Company
108 S DeLacey Ave.
PASADENA, CALIFORNIA

and contract machining.

Before coming to Shreveport, Mr. Russell was assistant general manager of the Turner Brass Works in Sycamore, Illinois, for three years. Previously, he had held executive posts in production departments of midwestern manufacturing firms.

Mr. Russell is a sustaining member of the Shreveport Section of the AMERICAN WELDING SOCIETY and is serving his second year as a member of the executive committee. He is also a member of the national nomination committee representing District 9.

Coxe Appointed

Handy & Harman has announced the appointment of Charles D. Coxe as manager, Metallurgical Department.

His responsibilities will include operation of the company's technical and assay laboratories, technical control in plants and powdered metal products manufacturing.

Mr. Coxe became affiliated with Handy & Harman in 1946 as chief metallurgist, Technical Laboratory. Subsequently he was made assistant manager, Metallurgical Department. Earlier, he had spent 10 years in research and development work with du Pont and Remington Arms Co., and three years with the steel industry.

He holds a degree in Metallurgical Engineering from Lehigh University.

Phillips Appointed Advertising Manager

Maurice J. Phillips has been appointed advertising manager of the International Nickel Co., Inc., Lars R. Larson, vice-president and general sales manager of the company, announced recently. He succeeds Robert L. Lloyd, who has attained retirement age.

Mr. Phillips has been with International Nickel since December 1920. He was placed in charge of direct mail circulation in 1926 and became assistant manager of the Advertising Section of the Inco Nickel Alloys Sales Department in 1934. Mr. Phillips was named assistant to Mr. Lloyd in November 1952, when the advertising sections of the Nickel Sales and Inco Nickel Alloys Sales Departments were consolidated into one department. He is a past president of the Industrial Advertising Assn. of New York and is at present a trustee of the Industrial Advertising Research Institute.

Cordovi Honored by ASM Chapter

Marcel A. Cordovi, head of the materials and testing department of The Babcock & Wilcox Co.'s Atomic Energy Div., has been named recipient of the second annual Industrial Achievement Award of the New York Chapter of the American Society of Metals. The award was presented to Mr. Cordovi at the SOCIETY's annual dinner held on March 11th at the Hotel Victoria in New York City.

Mr. Cordovi was born in Sofia, Bulgaria, on Nov. 17, 1915, and received his AB degree in general sciences and arts from the American College at Sofia in 1945. He holds BME, MME and ME degrees from the Polytechnic Institute of Brooklyn, and has studied metallurgical and mechanical engineering at the University of Michigan and the University of Pittsburgh. He is presently adjunct professor of metallurgical engineering at the Institute.

Mr. Cordovi was associated with the Welding Research Council for a number of years. Joining B & W's Tubular Products Div. in 1943 as research metallurgist, he was promoted to supervisor of research in 1946, and to staff metallurgical engineer, Boiler Div., in 1949. He was transferred to the Atomic Energy Div. in 1953.

He is author of more than 20 technical papers, many of them published in the *Welding Research Supplement*. He is also official United States representative to the International Institute of Welding.

Pierce and Iverson Appointed

E. R. Walsh, III, vice-president in charge of sales for Alloy Rods Co., recently announced these changes in the company's sales organization.

AT THE FRONTIERS OF PROGRESS YOU'LL FIND

FOR WELDING AND CUTTING...

IN THE RED DRUM

HIGHEST QUALITY

DUST-FREE

AN AIR REDUCTION PRODUCT

NATIONAL CARBIDE

Write for the name and address of the NATIONAL CARBIDE supplier nearest you.

National Carbide Company
GENERAL OFFICES: 150 EAST 42ND STREET, New York 17, N.Y.
A DIVISION OF AIR REDUCTION COMPANY, INCORPORATED

PAGE offers 3 big advantages

PAGE has unsurpassed facilities, experience and special skills for drawing and furnishing the right wire for your welding applications. We are ideally equipped to manufacture wire to any desired size, temper or surface finish.

We purchase our raw materials to rigid specifications; we select heats of steels for optimum characteristics—then, upon delivery and before processing, we analyze samples for conformity with our specifications. Thus, PAGE is *the one supplier* in a perfect position to control the chemical and physical properties of its product *from billet to rod to wire!*

1 Wire to Fill Your Needs —Wide Analysis Range

The PAGE line contains 26 *different analyses*, covering the field of applications: heavy automatic submerged arc...light manual submerged arc...inert gas manual ...automatic, tungsten or metal arc.

AUTOMATIC WELDING WIRE

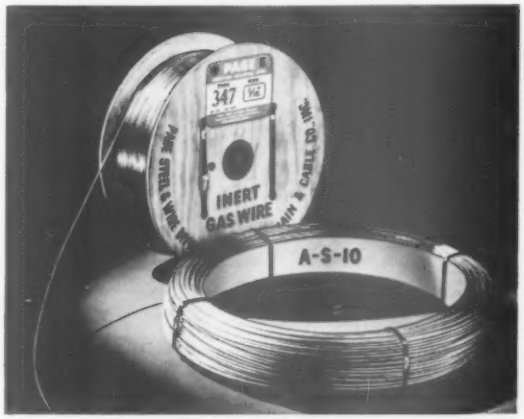
CARBON STEEL...Any carbon from Armco (.025 max.) to high carbon (.70-.84)

LOW ALLOYS...All the most popular welding grades

STAINLESS...All standard AISI grades. Other types on request

GAS WELDING RODS

PAGE Gas Welding Rods have long been recognized as the standard of quality, uniformity and dependable performance. These rods, in an exceptionally wide range, are furnished in coils, on reels or in 36-inch lengths, in the following materials: medium or high carbon steel, mild steel, Armco, low alloy, stainless steel, manganese bronze, naval bronze.



BARE ELECTRODES

PAGE Bare Electrodes are available in any carbon from Armco to high carbon (.70-.84).

METAL SPRAY WIRE

PAGE Metal Spray Wire is supplied in: any carbon from Armco to .80 carbon, low alloy, stainless steel, manganese bronze, naval bronze.

2 PAGE Packaging Means Protection and Convenience

Wrapped Coils... Coils in Cartons

Single and palletized coils, each coil steel-strapped and wrapped in waterproof paper...Also, single and palletized coils, in individual cartons.

Handy Reels

PAGE Inert Gas Welding Wire is available on 25-lb., nonreturnable palletized reels to fit all popular inert-gas welding machines. Wire is precision thread-wound.

Pay-off-paks & Leverpaks

PAGE *Pay-off-paks* permit *continuous feeding of wire up to 600 lbs.* (from 20″ *Pak*) *or 850 lbs.* (from 23″ *Pak*) *without rethreading.* Both *Pay-off-paks* and lightweight *Leverpaks* (*not illustrated*) give protection against distortion and corrosion...are easily opened, resealed, handled, stored. Palletized when requested.

Welding Wire in Coils

PAGE A-S Automatic Welding Wire is regularly furnished in layer-wound coils with cardboard liner, four Signode straps for easy coiling and unwinding —palletized as necessary.

Gas Rod Packing

PAGE Gas Welding Rods are supplied in 36″ lengths in 50-lb. bundles, paper and burlap-wrapped. Also in burlap-wrapped coils and 150-lb. (approx.) reels. Stainless rods also available in 10-lb. fibre-board cartons.

3 Prompt Delivery from Local Stocks

PAGE automatic arc welding wire and oxy-acetylene welding rods are readily available from PAGE warehouses shown at bottom of this page—and from a nearby PAGE Distributor, wherever you live. Your PAGE Distributor saves you time by filling your needs promptly from his stock. This helps keep your inventory investment down!

ACCO for Better Values

**Indicates PAGE warehouse stocks*

Send for These...

- **Folder DH-402A** • PAGE Submerged Arc and Inert Gas Welding Wire
- **Booklet DH-1277** • PAGE Gas Welding Rods
- **Welding Rod Comparison Chart**

Page Steel and Wire Division
AMERICAN CHAIN & CABLE

Monessen, Pa.*, Atlanta, Chicago*, Denver*, Detroit, Houston* Los Angeles*, New York, Philadelphia*, Portland, Ore. San Francisco*, Bridgeport, Conn.

ACCO

MANUFACTURING RESEARCH ENGINEER

• *Welding* •

Welding section of Manufacturing Research & Process Department has an excellent opportunity for a college graduate with BS in engineering or science, plus 3 years experience in welding. The applicant selected will conduct research and development programs in welding; also act as welding consultant to engineering, and apply welding processes for production. Experience in aircraft manufacturing preferred.

Salary commensurate with experience and ability to work with high degree of independence.

Among other advantages, Republic offers a comprehensive benefit program including company-paid hospitalization, surgical, accident and life insurance, tuition (½), 2-fold pension plan, individual merit rated increases and many other benefits.

Send resume in confidence to:

MR. PAUL HARTMAN

Employment Department

REPUBLIC AVIATION

Farmingdale, Long Island, N. Y.

John Pierce

Einar Iverson

John Pierce has been transferred to a territory in Southern California and will use the Alloy Rods Co. Pacific Coast division offices and plant in El Segundo as his headquarters. He formerly served the Indiana-Illinois area from the Chicago branch office and warehouse.

Einar Iverson has been appointed to the Chicago territory formerly filled by John Pierce. Mr. Iverson previously served Alloy Rods Co. distributors throughout the mid-west. Mr. Pierce is a member of the AMERICAN WELDING SOCIETY.

EMPLOYMENT SERVICE BULLETIN

Services Available

A-697-Experienced, capable, mature man, 46, desires position in either of following: 1. Sales, manufacturer or distributor of welding supplies and equipment. 2. Industrial position, supervisory capacity, specialized "know-how" including silver brazing alloys, fluxes and all other types of brazing materials and applications. Willing to travel or relocate if necessary. Special preference given to Eastern Seaboard Location.

PRESSURE VESSELS HEAT EXCHANGERS

New York area fabricating shop of 125 men offering well paying career opportunities in top management team to men of mature judgment & long experience in heavy steel, clad & stainless weldments & other alloy materials.

SHOP SUPERINTENDENT Assume full responsibility for all shop operations. Have actual working experience & similar supervisory background. Knowledge materials & manhours essential.

WELDING FOREMAN Supervise & instruct all welders. Must have adequate background in welding engineering.

CHIEF INSPECTOR Know ASME code & shop practices. Require inspection experience in our field. Send replies to Box V-342, The Welding Journal.

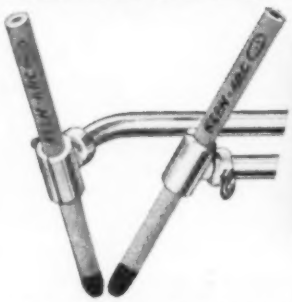
Advertising Rates

The Welding Journal

Effective June 1, 1955	1 time	3 times	6 times	12 times
Full Page	$305.00	$280.00	$265.00	$240.00
Two-thirds Page	215.00	200.00	185.00	175.00
Half Page	170.00	155.00	145.00	130.00
One-third Page	125.00	115.00	110.00	105.00
Quarter Page	100.00	95.00	90.00	85.00
One-sixth Page	75.00	70.00	65.00	58.00
Eighth Page	62.00	58.00	50.00	46.00
Special Preferred Positions: (Full Page)	335.00	310.00	295.00	270.00
COVERS 12-time contracts only:				
2nd cover				300.00
3rd cover				275.00
4th cover				325.00

BECKER

KEEN-ARC CARBONS



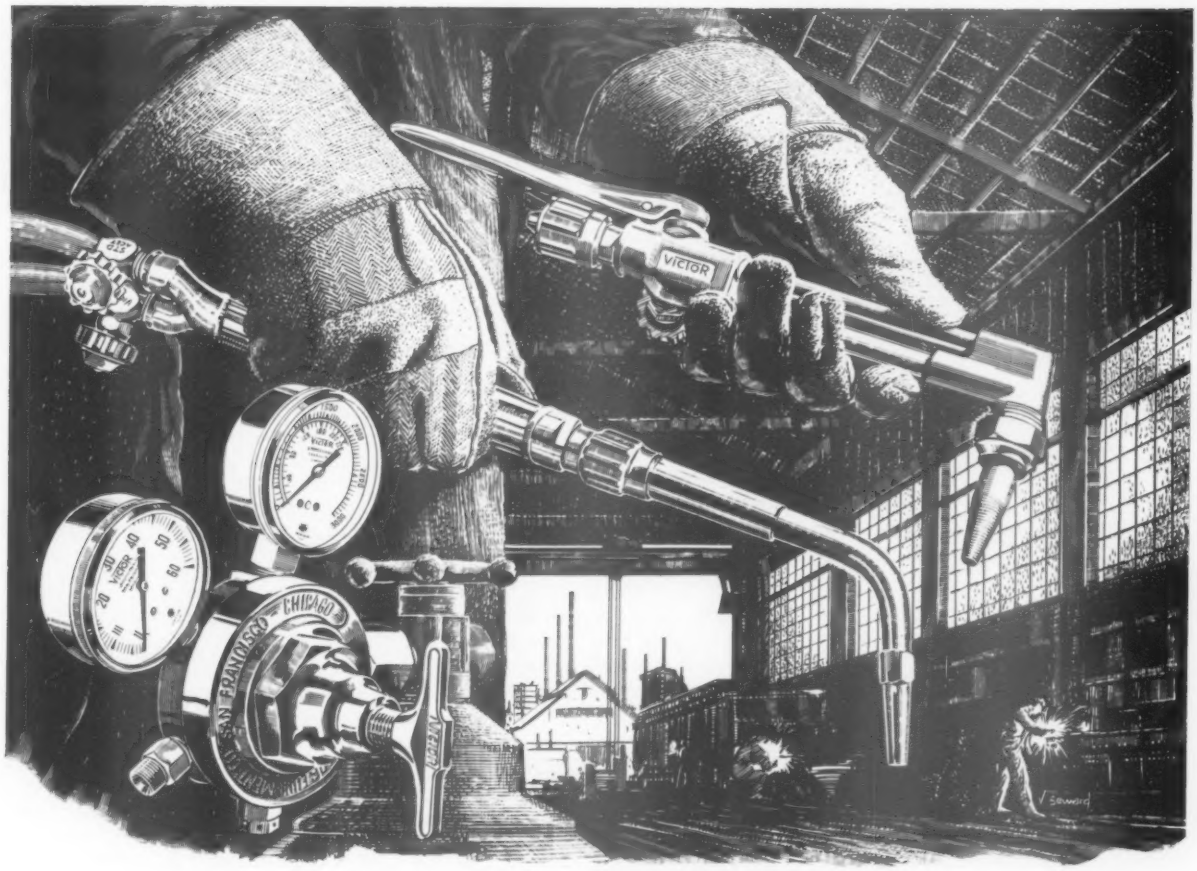
FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

BECKER BROTHERS CARBON CO.

3450 South 52nd Ave. Cicero 50, Illinois



the most flexible tools in the metal working industry

VICTOR COMBINATION WELDING & CUTTING UNITS

FOR EASE OF HANDLING DIFFERENT JOBS . . . Welding, brazing, hardfacing, heating, heat treating, descaling and paint burning. Cutting, trimming, deseaming and weld scarfing.

WITH A WIDE VARIETY OF NOZZLES, TIPS AND CUTTING ATTACHMENTS, with quick-change, hand-tight, time tested sealing ring connections.

RELIABLE FIELD-PROVED REGULATOR DESIGN for safe, dependable pressure and flow control.

See for yourself how easy it is to handle your work when you use Victor equipment. Ask your Victor dealer for literature or a demonstration.

VICTOR for welding

36

VICTOR EQUIPMENT COMPANY

Mfrs. of welding & cutting equipment; hardfacing rods, blasting nozzles; cobalt & tungsten castings; straightline and shape cutting machines.

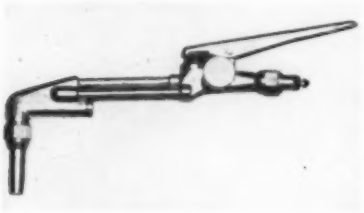
844 Folsom St., San Francisco 7 • 3821 Santa Fe Avenue, Los Angeles 58

NEW PRODUCTS

Cutting Attachment

A new light-duty oxyacetylene cutting attachment, the Airco Style 1490, is now available from Air Reduction Sales Co. This unit attaches to the Airco Style 400 lightweight welding torch.

The weight of the Style 1490 attachment is 13 ounces, and it measures 9½ in. in length. Cutting range is up to one inch thick steel. A firm gas-tight seal is assured with tapered gas sealing rings and hand tightening makes a firm joint.

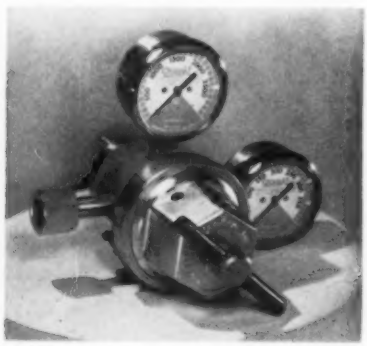


A diaphragm-type cutting oxygen valve eliminates the need for valve packing and prevents gas leakage.

Additional information can be obtained by writing Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 East 42nd Street, New York 17, N. Y.

CO_2 Regulator

A heavy-duty carbon dioxide regulator, the Oxweld R-69-400 has been introduced by Linde Air Products Co., a Division of Union Carbide and Carbon Corp. Designed for use on carbon dioxide cylinders or manifolds, the new regulator boasts the largest capacity and widest work range of any CO_2 regulator now available, according to manufacturer. Effective operation is possible at any delivery pressure up to 200 lb per sq in. These features combined with extremely sensitive control, are said to adapt the R-69 regulator to a wide range of applications.



The new Oxweld R-69-400 Regulator operates on a two-stage principle of pressure reduction.

For further information, write to Linde Air Products Co., 30 East 42nd Street, New York 17, N. Y.

Tilting Turning Rolls

The Aronson Machine Co., Arcade, N. Y. describes its Tilting Turning Roll as being truly "universal" in its application to the job. These tilting rolls can be used as plain turning rolls for work of any minimum length and up to 20 ft in length and from 4 in. in diam up to 6 ft diam. There are two pins to pull and a few bolts to loosen and the whole end stop mechanism can be removed. These rolls are manufactured in capacities from 5000 lb to 30,000 lb.

All models are supplied with an accurate protractor to indicate the degree of tilt, and with adjustable triggers to trip the precision limit switches at any preset degree of tilt.

The longest practical length of tank is 20 ft and still keep overhang within bounds of good practice. Other shorter lengths may require shorter tubular beams so as to reduce floor space required and to reduce the height required for full tilt.

For complete details, write directly to Aronson Machine Co. at the above address.

Flux-Coated Bronze Rod

A new flux-coated bronze rod for welding bronze and brass and braze welding cast iron and steel is announced by National Cylinder Gas Co., Chicago.

By eliminating hand fluxing the new rod, according to NCG, will cut welding time as much as 15%, will reduce gas consumption and improve the qualities of welds.

The rod, "Redifluxed" Bronze No. 30, is an all-purpose, low fuming, bronze. It melts at 1625° F, has good tinning qualities and produces high strength welds. It is made in 3/16 and 1/8 in. diam, packed in 10-lb tubes.

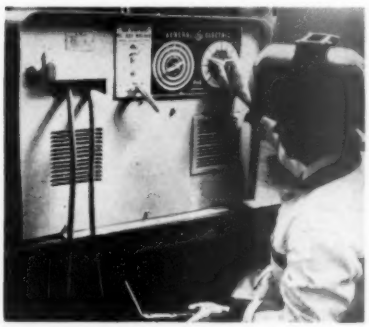
Demonstrations and samples are offered by National Cylinder Gas Co. dealers and by the company's offices in 56 cities.

Motor-Generator Welders

A new line of motor-generator welders, featuring pre-lubricated, sealed bearings, controlled current peaks, and space-saving design, has been announced by General Electric's Welding Department.

Its designers emphasize that, due to compact, sturdy construction, the welders may be stacked—one atop the other—thus reducing considerably floor space.

The welders are designated WD30AE and WD40AE. An improved magnetic starter with fast response, bi-metallic thermal overload relays prevents motor burnout in the event of motor overload. The relays will kick-out in less than ten seconds in stalled single phase, and in less than eight seconds if the rotor is locked in normal three-phase position.

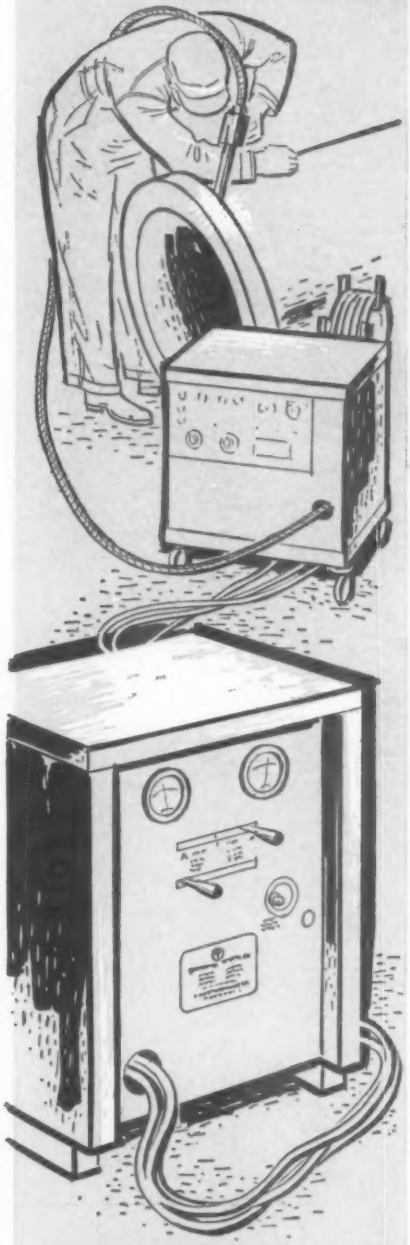


All bearings, which are rubber-mounted for quiet operation, are oversize for longer life. A unique air by-pass in the intermediate bearing housing and a dust cap on the commutator and bearing prevent dust contamination.

The new motor-generator welders can be used for virtually all industrial ap-

Welding Progress

at METAL & THERMIT CORPORATION • General Offices: Rahway, N. J.



WELDING SUPPLIES
PLATING MATERIALS • ORGANIC COATINGS
CERAMIC MATERIALS • TIN & TIN CHEMICALS
METALS & ALLOYS • HEAVY MELTING SCRAP

NEW WELDER FEATURES GREATER RANGE OF CURRENT DENSITY

The new M&T Controlled Arc Power Supply introduced by Metal & Thermit, delivers DC welding current at constant, preset voltages. A unique arc characteristic control provides a "cushion" effect especially desirable in low current density welding of light gauge metals. By reducing current surges, it permits deposition of more metal per pass with improved quality and appearance.

Built for long, trouble-free service, the M&T Controlled Arc Power Supply is rated at a full 100% duty cycle. When teamed with an equally rugged CAPS Constant Speed Wire Feed and gun, the combination provides a complete welding package. Low installation and power costs, simplified operation, and rugged, dependable, full-time service reduce overall costs for all types of semi- and full-automatic welding. For full details, write to Metal & Thermit, Rahway, N. J.

Faster Welding With Speedex

Featuring more pleasing arc characteristics, faster deposition rates, and more uniform deposits, the M&T SPEEDEX iron powder electrodes meet requirements for top quality weldments. Electrodes are available for both down-hand and all-position welding with AC or DC machines.

The SPEEDEX line includes electrodes for general use, and low hydrogen electrodes for hard-to-weld steels. The latter give fast deposition where high strength and dependability under great stress are important. Available through any Murex dealer, or write directly to Metal & Thermit.

Less Dilution of Weld Metal Improves Hard Facing

Improved quality and wearing characteristics of hard facing overlays are being obtained by manufacturers using the new line of Hardex hard surfacing electrodes with low hydrogen coatings. Results show a minimum amount of penetration, and therefore much less dilution of the deposit by the base metal; a weld metal of far less porosity; and greater freedom from cracking. The complete Metal & Thermit Hardex line offers hard surfacing materials alloyed for a wide range of applications.

A catalog describing these electrodes is available through Metal & Thermit.

plications, including light, medium, and heavy d-c metal-arc and inert-arc welding.

For complete details, write to General Electric Co., Welding Div., Schenectady 5, N. Y.

Fluxless Aluminum Solder

Wider use of aluminum in handsawable tubes, bars, shapes, etc. is foreseen in a fluxless aluminum solder announced by All-State Welding Alloys Co., Inc., 249-55 Ferris Avenue, White Plains, N. Y.

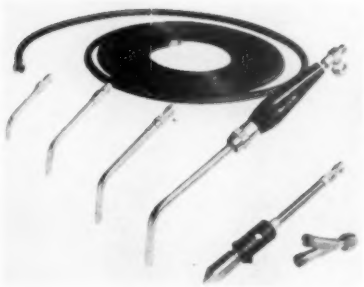
According to manufacturer, characteristics of the new solder that indicate this include: High strength—to 20,000 psi tensile in a mitered joint ... lead free ... no galvanic action between solder and base metal ... good color match with aluminum ... and low-skill applicability with any form of heat that will raise the temperature to 720° F, at which point the alloy flows freely.

Designation is All-State No. 55 Rubbon Aluminum Solder. The alloy is to be rubbed on without a flux.

Torch Handle for Air-Acetylene Outfits

Most precision model air-acetylene outfits manufactured by Linde Air Products Co., a Division of Union Carbide and Carbon Corp., are now supplied with the Prest-O-Lite No. 403 torch handle.

This handle is equipped with a needle valve to meet the requirements of those who prefer a valve at the rear of



the handle and have no need for a pilot flame. The No. 403 torch handle connects directly to standard $^3/_{16}$-in. Prest-O-Lite fitted hose assemblies through "A" size left-hand threads on the needle valve. Over-all length is $7^9/_{16}$ in.; weight is 10 oz. The No. 401 torch handle, with "gas miser" pilot flame control and forward shutoff valve, is still available as an optional accessory.

Complete details are available in a new catalog just published. Write Linde Air Products Co., 30 East 42nd Street, New York 17, N. Y. for a copy. Ask for F-6995.

Cable Splicer

Vulcanized, neoprene-insulated cable splices without power loss can now be produced, in the plant or in the field, in just five minutes with a new portable cable splicing kit, according to Cam-

Lok Division of Empire Products, Inc., Cincinnati, Ohio. The new 110-volt kit makes permanent cable splices which are reported to be flexible, waterproof and shockproof.

The new kit includes crimping press, cable cutter and vulcanizing mold, and can also be used to make Cam-Lok rubber insulated cable connectors.

Catalog and complete details on the new kit can be obtained from the manufacturer; Cam-Lok Division, Empire Products, Inc., P. O. Box 98, Cincinnati 36, Ohio.

"Brother, you haven't welded till you've tried this New SW2-M—in any position!—

EVEN VERTICAL DOWN!"

It's the greatest development in E-6013 electrodes since that great, original Westinghouse SW!

This new SW2-M has *extraordinary* arcing characteristics—*excellent* bead shape!—*effortless* slag removal! —*really* low splatter loss! It's the easiest handling electrode *ever!* More than that, *every operator who tries it* says, "The new SW2-M is *great!*"

"No kidding—you, too, will *have to weld* with this one to believe it! I promise you a big surprise when you weld with the new, Westinghouse SW2-M!"

NEW SW2-M ELECTRODES NOW IN STOCK! READY FOR IMMEDIATE SHIPMENT! Call in your order *today*...you'll *weld better tomorrow!*

J-22081

ONLY WESTINGHOUSE OFFERS THIS WELDING LEADERSHIP

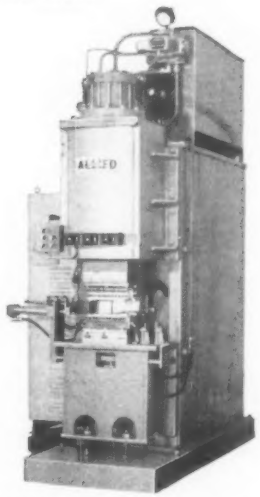
YOU CAN BE SURE...IF IT'S Westinghouse

Since you're looking for better tools . . .

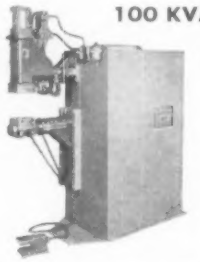
. . . LET'S TALK STANDARD WELDERS!

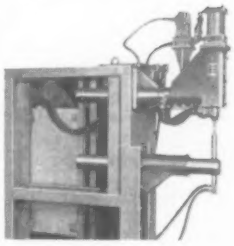
Allied's new roller head press type combination spot and projection welder (lower illustrations) has 8 outstanding advantages. Standard models are approximately one foot less in width than conventional welders, accomplished by placing arms off-center with controls installed within chassis frame where protected. Arms can be installed left or right of center making possible convenient welding of irregular-shaped pieces that fit naturally around corner of machine. Machines with right and left hand mounted arms may be installed adjacent to each other and within 9½" for sequence welding. Arms may be extended by simply loosening 3 screws on casting to give up to 30" throat depth. Vertical adjustment of lower arm up to 15" is provided without changing current characteristics except on air gap since transformer is connected directly to arm support casting instead of mounting plate. By removing 4 bolts, head may be replaced with special adaptations such as multiple guns or projection welding platens. This is done in minutes on the job. Welders are completely water cooled with open or closed circuits. Available in standard sizes: 30, 50 and 75 KVA with 1000 P.S.I. at 80 lbs. line pressure and 75, 100 and 150 KVA with 2300 P.S.I. at 80 lbs. line pressure and on up to 750 KVA in press welders (top). Prices are well below that of conventional welders of equal capacity.

750 KVA



100 KVA

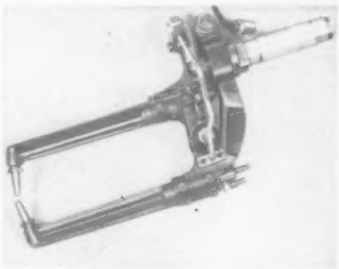


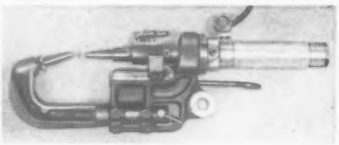


Write for information.

. . . LET'S TALK WELDING GUNS!

Operation so cool you can hold your hand on the jaw extension right below the point is main feature of this new line of portable guns. Incoming water reaches point through tube insulated almost its entire length from metal of jaw by return water jacket which has 5 times capacity of in-flow tube. Heat transfer to the in-flow tube is much less than with small diameter cast-in return water tubes that build up excessive heat in the jaw extension. Use contact fulcrum pin in place of conventional shunt which tends to overheat causing early failure Built-in guide for moving jaw prevents wear on fulcrum pin if gun is used in cocked position. Line includes "C" and scissors type with upper or lower jaw operating and types for special applications. Guns have been on heavy duty production test for 2 years.





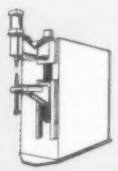
YOUR SPECIAL EQUIPMENT PROBLEM — *HOW BIG IS IT . . . REALLY?*

If it involves special equipment for a production welding operation it may not be a problem at all—just an assignment when placed in competent hands.

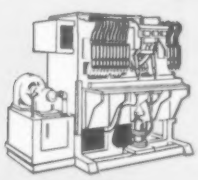
This is our kind of work—we specialize in it—do it every day; designing and building special machines for welding everything from bathtubs to trailers, frequently including provisions for automatic handling and transfer where the job is a part of a production line set-up.

We're no brain trust here at Allied Welder, but we keep some awfully important production people happy with our creative designing and manufacturing know-how—delivery, too.

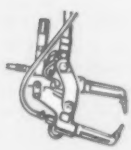
May we work with you on your next job?



Standard Welders



Special Welders



Automation Equipment

Automatic Arc Welders

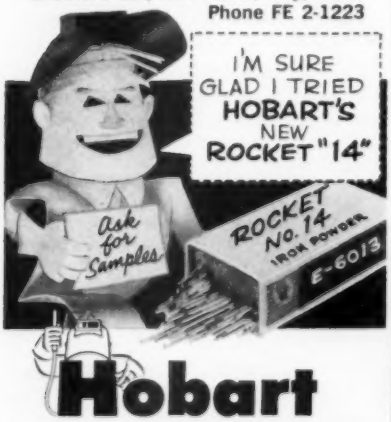
Welding Guns

ALLIED WELDER CORPORATION

8700 BRANDT DEARBORN, MICHIGAN

Creative Design

An outstanding new general purpose electrode for AC or DC with a soft, stable arc for all position welding. A new development in iron powder electrodes for higher currents and faster welding. You'll be amazed how simple and easy it is to use. You'll like the "drag" or "short arc" technique and the greater speed that means lower welding costs for you. You can't afford to overlook the advantages of Hobart "Rocket 14." Takes only a few minutes to prove to yourself on your own work. Hobart Brothers Co., Box WJ-571, Troy, Ohio, Phone FE 2-1223



Hobart

to: HOBART BROTHERS CO., Box WJ-571, TROY, O.

- ☐ Send information on "Rocket 14."
- ☐ I would like to try some samples.
- ☐ Send complete catalog on electrodes.
- ☐ Send catalog on arc welding machines.

Name_____

Street_____

City_____ County_____ State_____

Portable X-ray Unit

A new X-ray unit for portable radiographic inspection is being introduced by the Balteau Electric Corporation, Stamford, Conn.

Called the Baltospot 200, this new machine is said to feature low cost and a high degree of portability. With a rated capacity of 200,000 volts, the X-ray head weighs only 85 lb, which provides a very low weight-to-power ratio.

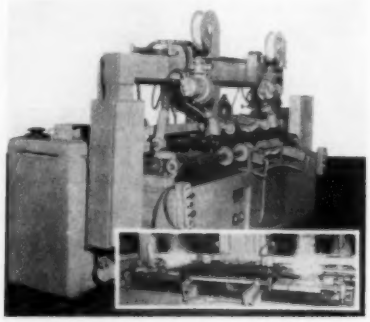
The range of material it will radiograph extends from thin magnesium sheet to 3 in. of steel.

Write to Balteau Electric Corp. at above address for complete details.

Co_2 Automatic Welder

An automatic truck drive tube CC-2 welding machine of marked flexibility has reportedly been designed and built by Dix Engineering Co., Inc., (Detroit) Lincoln Park, Mich.

The new machine was custom made for a leading motor truck manufacturer. Its design met the customer's problem of speeding the welding operations on the drive shafts for their trucks.

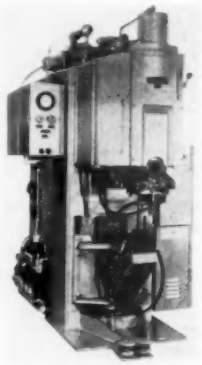


In the course of the machine's operation the universal joint assembly is welded to the drive tube at one end with a continuous weld bead around the diameter. At the same time the driving splined shaft is welded into the drive tube at the other end.

For complete details, write directly to Dix Engineering Co. at above address.

Spot Welder

The Taylor-Winfield Corp., Warren, Ohio, announces the availability of their special press-type spot welder which welds heavy gages of aluminum alloy,

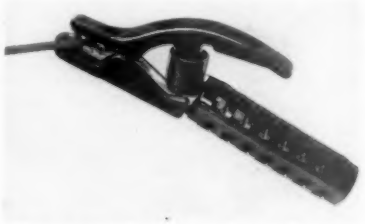


heat-resisting alloys, and stainless and low-carbon steels, according to military specifications. It is a special Size 4, 200 kva tri-phase welder, hydraulically operated with 18,000 lb maximum force at 30 in. throat.

For additional information, write directly to Taylor-Winfield Corp.

Electrode Holder

A new "Tong-Grip" electrode holder, which successfully delivers 300 amps on a heavy-duty cycle when connected to a 00 cable, has been introduced by Martin Wells, Inc., 5886 Compton Avenue, Los Angeles 1, Calif. Weight is 17 oz.



It features all glass insulators and spring cup; patented slip-on insulator—with no screws or rivets; patented feature of no current in hinge pin or upper tong; patented wedge cable connector makes perfect and permanent connection on first installation. Holder is rugged and has only nine parts.

For complete details, write directly to manufacturer at above address.

Welding Positioner

The new Rexarc RP-73-X automatic welding positioner for welding crawler-type tractor rollers, idlers and other circular or conical objects, is designed for use with longitudinal tractor rail welding machines.

The RP-73-X is attached to the end of the longitudinal rail welder so that the welding of circular objects can begin

HARRIS TORCHES reduce fuel costs 97.01%

Cutting steel risers at the Unitcast Corporation of Toledo, Ohio was a costly and time consuming operation. In an effort to solve this problem, Unitcast recently replaced fifty torches with equipment from Harris Calorific for use with natural gas.

These Harris torches are unique in that torch and tip are *both* designed for use with natural gas. As a result, fuel costs have been reduced from 77¢ per hour to .023¢ per hour. Also, the time required for a single operation has been reduced 13%.

The additional savings of the costly storing of carbide, charging the generator and sludge disposal have convinced Unitcast Corporation that there is no more economical . . . or efficient method of flame cutting than with Harris Calorific torches and natural gas.

Harris Calorific salesmen are well trained specialists who can help you solve your flame cutting problems. They have complete information to answer *all* your questions about gas welding and cutting equipment.

Call or write today!

HARRIS

HARRIS CALORIFIC CO.

5501 CASS AVE. • CLEVELAND 2, OHIO

The NEW LOOK

Comes To

CHAMPION!

Look For **CHAMPION**
WELDING ELECTRODES
in this bright new carton

Please bear with us as we convert to new containers for **CHAMPION WELDING ELECTRODES.** The same peak quality remains in every box—identified by the diagonal green and yellow stripes.

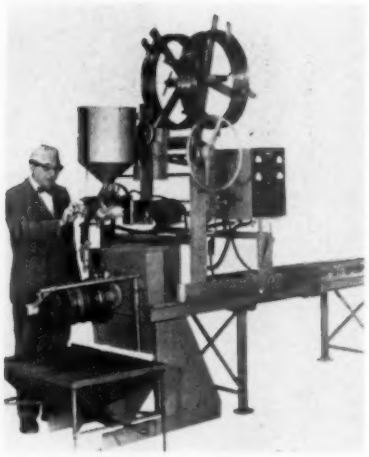
Whatever your requirements in Mild Steel, Low Alloy, Stainless or Hard Surfacing—**CHAMPION** has a superior product. See your sales agent or distributor or write us directly.

NEW CATALOG No. 57-A
JUST OUT!

Be sure you have a copy. Letterhead requests filled promptly. *Write today.*

THE CHAMPION
RIVET COMPANY

Cleveland, Ohio East Chicago, Indiana



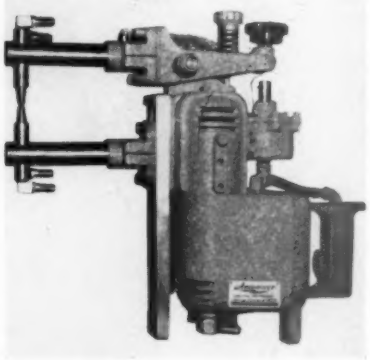
without shifting the welding head, control box or welding apparatus. Unit tilts easily for flange or flat circular work.

For complete details write to The Sight Feed Generator Co., 38 E. Third St., West Alexandria, Ohio.

Portable Resistance Welder

Model 57, latest development by Ampower Products Co., Oak Lawn, Ill., in the field of portable resistance welders, is now in production and ready for distribution.

Model 57 is described as having all the extra features of high priced, heavyweight production welders with one important additional feature—"portability." The new unit is water-cooled, air-powered, versatile and rugged.



The welder transformer is moisture resistant. The secondaries are heavy copper bars with hollow centers running the entire length for water cooling. The welder primary is completely isolated from the housing and the arms.

For complete details, write to Ampower Products Co., P. O. Box 464, Oak Lawn, Ill.

Flash Butt Welder

The special Taylor-Winfield flash butt

No. 602-3-C with #1085
Insulated Steel Glass Holder

No. 706-3-C with #1096
Insulated Dowmetal Lift-Front Glass Holder

FIBRE and FIBERGLAS* HELMETS

Inside view showing INNER BIB of Series "600" Helmets for extra protection to welder's neck from flashes and reflected glare.

New Series "400" Helmets. Smaller size for close quarter work.

*OWENS-CORNING TRADE MARK

Safety and comfort mean *more* welding . . . more production per day! Fibre-Metal engineering has for 50 years kept these "qualities" uppermost in mind . . . for more and better *work ability* by the welder.

Fibre-Metal's Helmets of Fibre *or* Fiberglas* are light, durably resistant to impact and hard use. They feature seamless compression-molded shells, beaded edges for strength and safety, Wide Range Headsize Adjustment, new 4-Position Helmet Stop, and provide for four popular glass holder styles. Adjustable friction joints hold helmet in any position.

Fibre-Metal Features:

LIGHT WEIGHT • EXCEPTIONAL STRENGTH • MOISTUREPROOF
NON-WARPING • HEAT RESISTANT (SELF EXTINGUISHING)
EASILY STERILIZED

When buying any welding equipment . . . always ask for a FIBRE-METAL product!

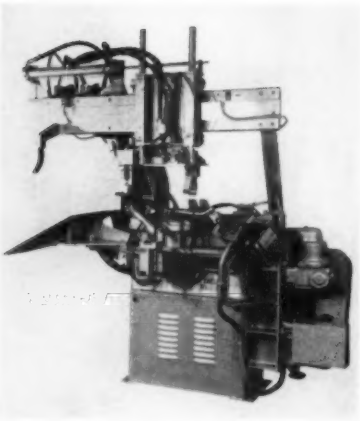
FIBRE-METAL
PROFIT ABLE, PROTECTIVE PRODUCTS SINCE 1905

WORKER SAFETY PAYS DIVIDENDS

THE WORLD'S LARGEST MANUFACTURER OF SUPERIOR PROTECTIVE EQUIPMENT

THE FIBRE-METAL PRODUCTS COMPANY
CHESTER, PENNA.

Sold Everywhere thru leading Distributors and Dealers



welder shown in the accompanying photograph joins the ends of long curved tubes that form part of an automobile exhaust cross over assembly. It is reported to weld the parts at a rate of 240 an hour. Upper structure is a pickup and transfer mechanism for automatic unloading. Special tooling includes motor-driven upset and horizontal air clamp. It is rated at 75 KVA.

For complete details, write to Taylor-Winfield Corp., Warren, Ohio.

Welding Power Supply

A new d-c stored-energy power supply for use in high production precision welding has been added to the line of small parts resistance welders made by Raytheon Manufacturing Co., Commercial Equipment Div., Waltham, Mass. Rated at 18 watt-seconds, the new 18A power supply is equivalent to a 5.8KVA

a-c system, but the use of the stored energy principle eliminates the need for high current capacity power lines, the manufacturer reports. Consistent Welds at rates up to 250 per min are said to be possible with the new unit which also can join metals of high electrical or thermal conductivity.

Write to Raytheon Manufacturing Co. at above address for further details.

In a board walk the largest item of expense is the lumber; in a splendid violin the least item of expense is the lumber.

In a plain wall the stone is the chief cost; in a piece of classic statuary the cost of the stone is hardly reckoned.

This principle, in a certain degree, applies to the making of a good positioner. We do not pretend that we put more or less material into each Aronson Positioner; but we do put in the best materials, the scientific knowledge and expert skill and the long-continued care which no ordinary positioner contains.

If you want to get rich music or a treasure of the sculptor's art or a job of positioning that will be satisfactory and increase your profits, you must pay for something other than raw material.

Aronson MACHINE COMPANY
ARCADE, NEW YORK

Here's Just 3 Reasons Why So Many Welder's Have Switched

- Wrap around Glass Fibre Tip Insulation—30% *more* heat resistance than any other make!
- Brilliant Red Tips and Trigger—Bright Yellow Handle—all Glass Fibre, an outstanding Safety Feature!
- Body completely insulated—no bare spots!

HI-AMP®
ELECTRODE HOLDERS
are the most economical to buy and maintain too!

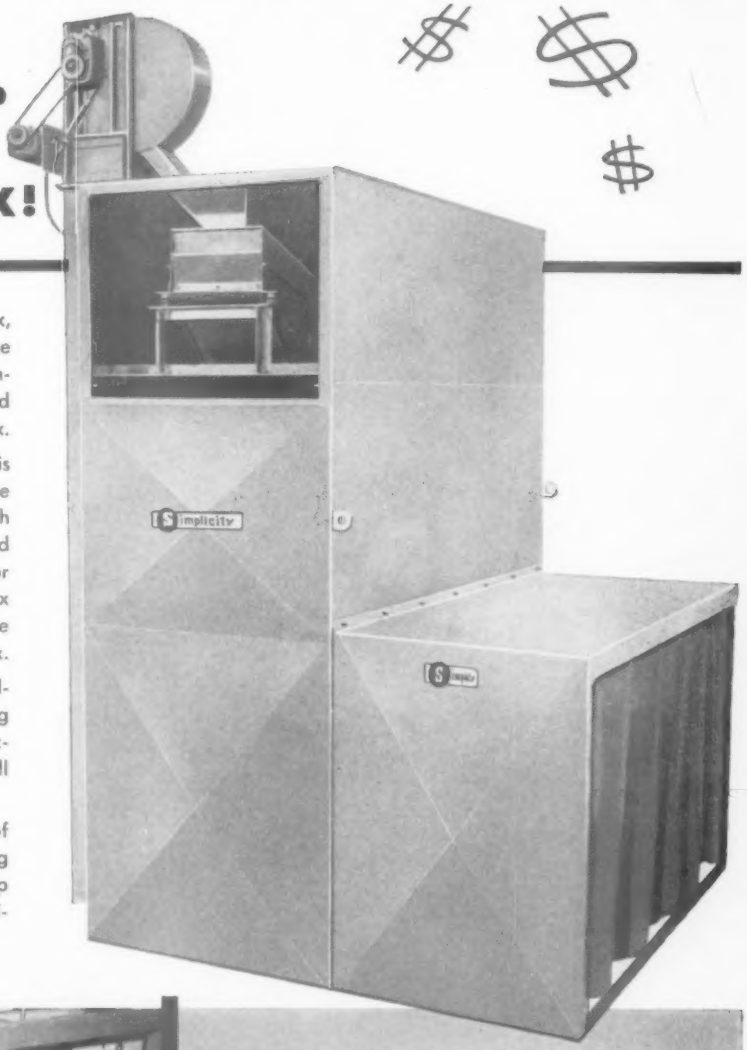
Just ask any Welding Supply Dealer anywhere for PROOF of the above statements.

LENCO, INC.
(Formerly Wagner Mfg. Co. Inc.)
JACKSON, MISSOURI

Weld with HI-AMP

THROWING MONEY AWAY?

YOU ARE, IF YOU SCRAP SPILLED AND FUSED FLUX!

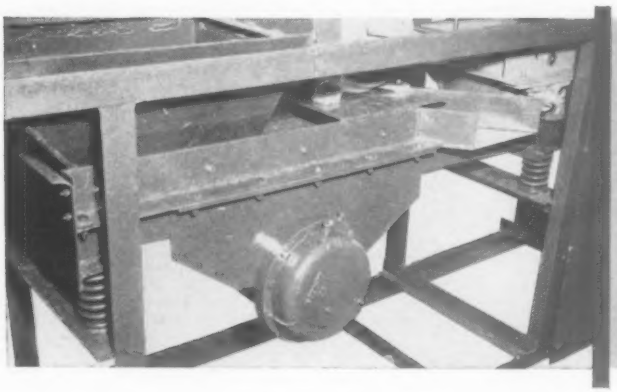


When you discard spilled and fused flux, you're throwing profits to the wind. A large automotive plant solved this problem by installing the Simplicity Flux Reclaim Unit, and saving $5,000 a month salvaging used flux.

Sound good? It should, if your plant is equipped with submerged arc welders. The Simplicity Flux Reclaimer is designed to crush used flux, remove metal particles, dust and fines, and give you refined flux ready for re-use. Mixed in proper ratio with new flux (depending upon type of work) welds are obtained equal to those made with new flux.

Equipped with a two surface vibrating feeder, bucket elevator, double deck vibrating screen, 15" x 9" crusher and two magnetic-pulleys, the Simplicity Flux Reclaimer will more than pay its own way.

Complete installation drawings and prices of these SIMPLICITY units may be had by writing directly to the factory . . . a logical first step in determining ALL the money-saving possibilities these machines may hold for you.



View of 12" x 4'9" two surface oscillating feeder, showing side discharge for removing scrap, metal particles and other foreign objects.

195

SALES REPRESENTATIVES IN ALL PARTS OF THE U.S.A.
FOR CANADA: Simplicity Materials Handling Limited, Guelph, Ontario.
FOR EXPORT: Brown and Sites, 50 Church Street, New York 7, N. Y.

Simplicity
TRADE MARK REGISTERED

ENGINEERING COMPANY • DURAND 23, MICHIGAN

NEW LITERATURE

Welding Directory

The first edition of the Welding Directory has been announced by the Industrial Publishing Corp., Cleveland, Ohio. The corporation also publishes Industry & Welding and Welding Illustrated Magazines.

The Directory will cover products, processes, sources of supply and reference data covering welding, cutting and brazing.

Scheduled for publication on Dec. 1, 1957, the Directory will be arranged in six conveniently tabbed sections: a directory of welding, cutting, brazing and auxiliary products; where to buy such products; a manufacturers' catalog section; where to buy products locally; product trade names index; and finally, a reference manual of welding, cutting, brazing and application data.

Industry-Education Cooperation

The International Acetylene Association has recently released a booklet entitled "More Scientists Through Industry-Education Cooperation." Its contents show how educators and men of industry can plan and work together, first to recognize, and then to solve their mutual problems in furthering the education of students equipped for careers in science or engineering.

The IAA has distributed over 40,000 copies of this booklet to leaders in the field of education and to significant executives in industry who are interested in education and who are in a position to influence favorable industry-education cooperation. Some additional copies are still available and may be obtained, in reasonable number, by writing to International Acetylene Association, 205 East 42 nd St., New York 17, N. Y.

Hard-Surfacing Wires

A new edition of the folder describing the hard-surfacing wires for semiautomatic application has recently been issued by Stoody Co. It contains data on welding characteristics, suggested uses of the 11 wires listed and general information on the semiautomatic process. This folder is available from Stoody dealers throughout the United States and Canada or may be obtained on request to Stoody Co., Whittier, Calif.

Welding Positioner

A new 16-page Bulletin No. UB57 featuring the patented Aronson Universal Balance Positioner is available from Aronson Machine Co., Arcade, N. Y. Five models with capacities of 25- to 2000-lb schematic drawings, complete specifications and optional accessories are included.

Write directly to company for your copy.

Controlled-Arc Power Supply

Details about simplified automatic and semiautomatic welding are described in a brochure about the new M&T Controlled Arc Power Supply. This rectifier-type welder supplies current at preset constant voltages to assure more uniform bead shape, according to manufacturer, Metal & Thermit Corporation.

Used in conjunction with a constant speed wire feed, the C.A.P.S. unit is said to automatically provide constant arc length, eliminating costly and time-consuming variables in operation. Stubbing and burn-back are reportedly eliminated.

The M&T Controlled Arc Power Supply is described as being adaptable to various automatic and semi-automatic welding requirements. It has the speed and range for such applications as submerged arc, inert gas and hard surfacing semi- or full-automatic welding

Free literati re is available upon request from Metal & Thermit Corp., Rahway, N. J.

Reports on 6066 Armed Forces Research

The following report of recent research for the Armed Forces has just been made available for industry use through the Office of Technical Services, U. S. Department of Commerce:

"Mechanical Property, Corrosion and Welding Studies on 6066 Aluminum Alloy," J. D. Wood, Wright Air Development Center. June 1956. 36 pages. $1. (Order PB 121497 from OTS, U. S. Department of Commerce, Washington 25.) Aluminum alloy 6066, an aluminum-magnesium-silicon-copper-manganese-chromium alloy, was evaluated as a material for use in Air Force weapons systems. Extrusions exhibited mechanical properties superior to 6061T6 alloy and approached those of 2014T6 extrusions. Laboratory rolled sheet of 6066T6 was substantially isotropic in directional properties and possessed strength almost equal to the 6066T6 extrusions. Stress corrosion life was found to exceed 2943 hours, although the elongation was decreased to about two percent after exposure. Exposure to salt spray indicated that the alloy should be protected against severe corrosive media by such means as cladding or anodizing and painting. Based on limited welding tests, 6066 can be arc welded using 6066, 716 and 195 alloy filler metals.

Water-Proof Cable Connectors

Neoprene-insulated heavy-duty cable connections can now be made on the job or in the field in minutes, according to an announcement by the Cam-Lok

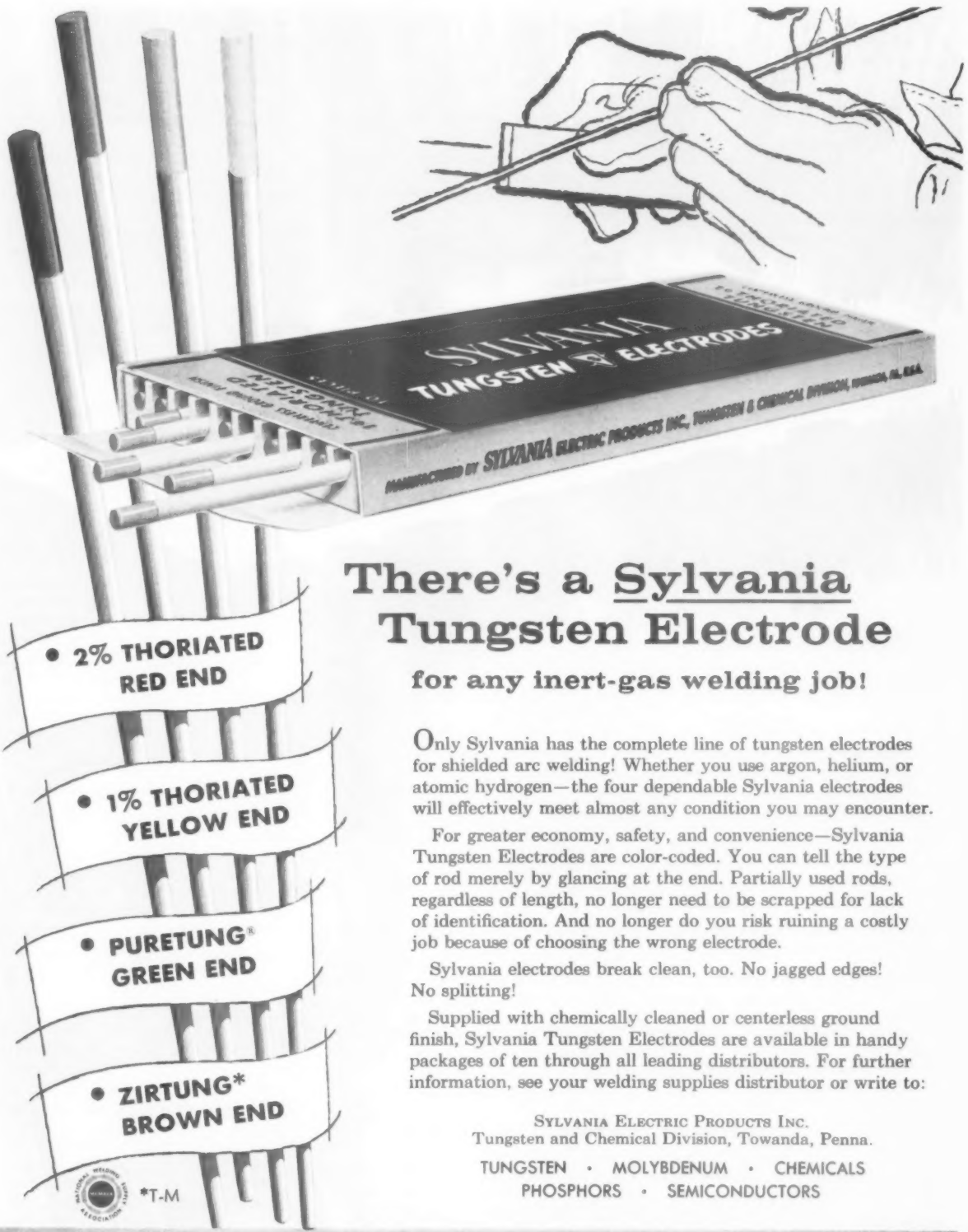
Division of Empire Products, Inc. This new development is made possible by a 110-volt, portable molding kit.

The new kit permanently seals metal connectors and electrical cables in neoprene rubber sleeves in only five steps. No training or experience is said to be required to operate the kit successfully. When the connectors and sleeves are inter-locked, the connection is completely water-proof, shock-proof and tight-locking, yet may be instantly disconnected. It may be safely used outdoors in any kind of weather.

A 4-page catalog No. 131, containing complete information on the kit and accessories, is available from the manufacturer, Cam-Lok Division, Empire Products, Inc., P.O. Box 98, Cincinnati 36, Ohio.

Brazing Alloys

A new four-page 8½ x 11 illustrated two-color catalog (SD-23) describing the Nicrobraz family of high-temperature brazing alloys and related materials of stainless steels and special alloys is now available from Stainless Processing Div., Wall Colmonoy Corp., 19345 John R. Street, Detroit 3, Mich.


SYLVANIA
TUNGSTEN ELECTRODES
MANUFACTURED BY SYLVANIA ELECTRIC PRODUCTS INC., TUNGSTEN & CHEMICAL DIVISION, TOWANDA, PA., U.S.A.
• 2% THORIATED RED END
• 1% THORIATED YELLOW END
• PURETUNG® GREEN END
• ZIRTUNG* BROWN END
*T-M

There's a Sylvania Tungsten Electrode

for any inert-gas welding job!

Only Sylvania has the complete line of tungsten electrodes for shielded arc welding! Whether you use argon, helium, or atomic hydrogen—the four dependable Sylvania electrodes will effectively meet almost any condition you may encounter.

For greater economy, safety, and convenience—Sylvania Tungsten Electrodes are color-coded. You can tell the type of rod merely by glancing at the end. Partially used rods, regardless of length, no longer need to be scrapped for lack of identification. And no longer do you risk ruining a costly job because of choosing the wrong electrode.

Sylvania electrodes break clean, too. No jagged edges! No splitting!

Supplied with chemically cleaned or centerless ground finish, Sylvania Tungsten Electrodes are available in handy packages of ten through all leading distributors. For further information, see your welding supplies distributor or write to:

SYLVANIA ELECTRIC PRODUCTS INC.
Tungsten and Chemical Division, Towanda, Penna.

TUNGSTEN · MOLYBDENUM · CHEMICALS
PHOSPHORS · SEMICONDUCTORS

SYLVANIA

Lighting • Radio • Electronics • Television • Atomic Energy

The new catalog discusses the characteristics and physical properties of Nicrobraz brazing alloys.

Surfacing Electrodes

"Rexarc Engineered Toughness" is the title of a new 20-page manual on Rexarc hard-surfacing and manganese electrodes being made available by the manufacturers, The Sight Feed Generator Co., West Alexandria, Ohio.

A comprehensive procedure section artistically illustrates many typical buildup and hard-surfacing applications for better wear resistance. Recommended application procedures are shown, together with the type and quantity of material required, and the range of machine settings for each.

In addition, an elaborate Directory of Uses, by industries, features an alphabetical list of worn parts that can be rebuilt, and names the proper electrode for the purpose. The manual presents many aids to the welder, though it is not intended to instruct in welding fundamentals.

Data Folder on Alloys and Fluxes

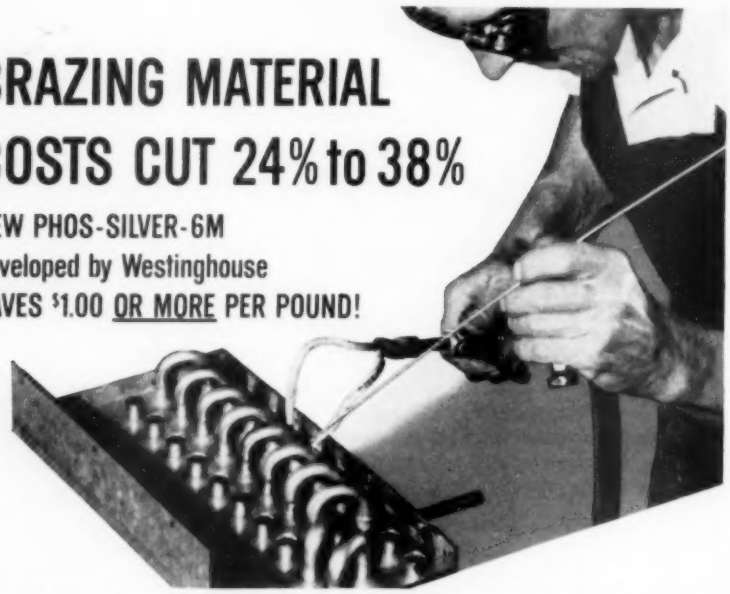
A new data folder for office use (6 pp., 8½ x 11 in., 3-hole punched) issued by All-State Welding Alloys Co., Inc., 249–55 Ferris Avenue, White Plains, N. Y., condenses into ready reference form the considerable data needed by buyers of specialty alloys and fluxes to help them make the wisest choices for their particular applications.

Rapidity of metallurgical and chemical developments affecting the welding, brazing, soldering, cutting and tinning of metals, makes this publication of timely interest wherever such supplies have to be specified and bought for use in maintenance, production or construction.

Copies are available on request, and without obligation, from All-State Welding Alloys Co. at above address.

BRAZING MATERIAL COSTS CUT 24% to 38%

NEW PHOS-SILVER-6M developed by Westinghouse SAVES $1.00 OR MORE PER POUND!



There is now a brazing alloy *proving* itself *superior* to brazing materials costing *3 to 4 times as much!*

It is the new Phos-Silver-6M—made by *extrusion* methods!—*blanketed* under *inert gas!* This eliminates the oxides that cause most brazing troubles. And produces *new versatility* in a brazing rod, with *exceptional* flow characteristics, *remarkable* ductility, and *unsurpassed* appearance of the finished work!

Moreover, Phos-Silver-6M (as *all* the new Westinghouse alloys), has been proved throughout stringent laboratory and shop tests, toughest production runs! Then, is now ANALYSIS CERTIFIED!—*assuring you* the *same consistent, best possible* brazing results!

Order *trial* packages *now!* You'll *standardize* on Westinghouse Brazing Materials *tomorrow!* J-22082-A

YOU CAN BE SURE...IF IT'S Westinghouse

This exclusive Westinghouse Seal "guarantees" you the correct formulation of every rod!

Convenient packaging, 18" lengths, 1-lb and 5-lb tubes. Standard 25-lb package, 36" lengths.

Select from the Westinghouse MOST COMPLETE LINE OF BRAZING MATERIALS IN THE INDUSTRY!

Phos-Copper®, Phos-Silver #2, Phos-Silver*, Phos-Silver-6M, Phos-Silver-15. These round, extruded rods give approximately 20% *more feet per pound* than square rods of the same diameter! (Same alloys also available in rod form, wire in coils, or rings.)

POWER-UP with Westinghouse *advanced* brazing materials!

*Trade-Mark

Three-Phase Resistance Welding Machines

New Tri-Phase Bulletin describes three-phase resistance welding machines produced by The Taylor-Winfield Corp., Warren, Ohio. The bulletin lists locations and production conditions suitable for three-phase welders. It explains Tri-Phase operational principles, describes associated control equipment and illustrates in-plant use of Tri-Phase welders.

A copy of this bulletin may be obtained by writing directly to Taylor-Winfield Corp. at above address.

Controlled-Atmosphere Chambers

A 20-page technical bulletin describing typical "packaged" controlled-atmosphere vacuum chambers is now available from Leader Welding & Manufacturing Co., 2418 Sixth St., Berkeley 2, Calif.

Specifications and complete description of standard "Leader" chambers for controlled-atmosphere welding and metallurgical research are included.

New booklet describes Leader expandable chambers with matched vacuum pumping units, instrumentation and controls, and various accessories and attachments available for controlled-atmosphere welding and metallurgical research. Copies may be obtained by writing manufacturer.

Steel Catalog

Crucible Steel Co. of America announces the availability of a new 232-page Product & Warehouse Catalog.

Designed for purchasing agents and steel users, the catalog describes over 700 products available from stock at Crucible warehouses located throughout the country.

The book index lists 16 categories of

special purpose steels, including high speed, tool, stainless, alloy and machinery, available in 16,000 grades and sizes. Over 20 estimating, conversions and weight tables as well as other information useful to steel users are also included.

A copy of the catalog may be obtained by sending a request on company letterhead to Engineering Service Department, Crucible Steel Co. of America, Box 1558, Pittsburgh 30, Pa.

Conversion Factors Chart

A reference table for engineers and other executives in wall chart form has been published by Precision Equipment Co. Included are common conversions such as inches to centimeters or watts to hp as well as many conversions that are difficult to locate in reference manuals. (Some such examples are atmospheres to Kgs/sq. cm, cm/sec to miles/-hr, cu ft to liters, microns to meters, quintal to lb, etc., etc.)

For your free Wall Chart of Conversion Factors, write Precision Equipment Co., 3716 N. Milwaukee Ave., Chicago 41, Ill.

Automatic Equipment

"Rexarc Keeps Earth-Moving Equipment Rolling," is the title of a new 14-page brochure on Rexarc automatic welders and positioners, and components manufactured by The Sight Feed Generator Co., West Alexandria, Ohio.

Especially designed for earth-moving contractors, and welders alike, the profusely illustrated brochure shows the remarkable versatility of the equipment for handling varied welding requirements by the submerged-arc method.

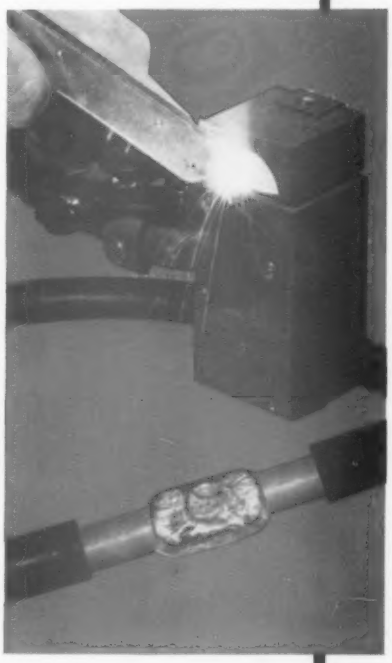
The new equipment featured includes a roller and idler welder and positioner capable of handling eight tractor rollers at a time, a rail welder attachment for varied circular and conical weldments, as well as numerous added features on Rexarc welding equipment.

For your copy, write directly to the manufacturer at above address.

Resistance Welding Machines

New Special Machine Bulletin describes 32 multispot and projection resistance welding machines produced by The Taylor-Winfield Corp., Warren, Ohio. The bulletin lists for each welder: end product, type of operation, production rate and associated materials handling equipment. Products covered include automotive parts, appliances, precision instruments, electric motors and basic steel.

For a copy of this Bulletin, write to Taylor-Winfield Corp. at above address.



Aye Laddie use CADDY®

be thrifty – use CADDY® cable splicing with CADWELD® connections

With a CADDY Cable Splicing Kit you no longer throw away those broken or short lengths of cable – CADWELD the joint and vulcanize or hose and punch-lok band over the 100% efficient connection. Keep your circuit in number one shape at all times – use less current and get the most out of your welding dollar.

CADWELD Connections are used on all CADDY ARC WELDING ACCESSORIES

CADDY®

ARC WELDING ACCESSORY DIV.

Erico Products, Inc.

2070 E. 61st Place • Cleveland 3, Ohio

IN CANADA: WELDING PRODUCT SALES, Canadian General Electric Co., Ltd. 1350 Castlefield Ave., Toronto, Ontario

Aluminum-bronze centrifugal castings welded at high speed

MIG-welded automatically with AMPCO-TRODE* 160 Spooled Wire

In string-bead welding this large paper-mill breast roll, wire feed was 88 inches per minute; travel, 15 inches per minute. There was no oscillation or peening, no burnback. No pre-heating was necessary — weld metal flowed uniformly into side walls and adjoining beads.

With layer-level wound Ampco-Trode 160 wire, you get fast, easy welds on overlays and many hard-to-join, dissimilar metals. Deposits have high strength, resist squashing-out in bearing service, and resist corrosion.

Order Ampco-Trode 160 Spooled Wire from your nearby Ampco distributor. Or mail coupon below today.

Sole producer of genuine Ampco Metal

AMPCO METAL, INC.,
Dept. WJ-5, Milwaukee 46, Wisconsin
West Coast Plant: BURBANK, CALIFORNIA

*Reg. U. S. Pat. Off.

W-146

Tear out coupon and mail today!

AMPCO METAL, INC.
Dept. WJ-5, Milwaukee 46, Wis.

Send me Bulletin W-17 for further information on Ampco-Trode 160 Spooled Wire and other Ampco electrodes.

Name_____

Company_____

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City_____ Zone____ State_____

REVIEWS
OF NEW BOOKS

Arc Welding Handbook

The Procedure Handbook of Arc Welding Design and Practice. Eleventh Edition. Over 1300 pages with 1100 illustrations, pictures and charts; 6-in. x 9-in. size; gold embossed simulated leather cover; price $3.00, postpaid in USA, $3.50 elsewhere. Publisher, The Lincoln Electric Co., Cleveland 17, Ohio.

This is a major revision of the well-known arc welding reference book. A major portion of the book has been completely rewritten. All of it has been closely reviewed and brought up-to-date.

The book is arranged and written as a reference book covering all phases of arc welding. Its contents range from the early history of arc welding to the intricacies of structural design. The eight sections are divided by subject matter for easy study. The eight sections are: history, nomenclature and processes, weldability, mild steel procedures, manufacturing cost data, machine design, structural design, applications and reference data.

The 465-page structural section has been completely rewritten and includes the latest data on welded design, as found in recently built structures and current research. There is a discussion of the theory and application of the rigid frame and plastic design systems. Details on the design of structural members and joints are included. A group of charts and nomographs simplify design calculations. Applicable codes have been condensed to usable size and are included.

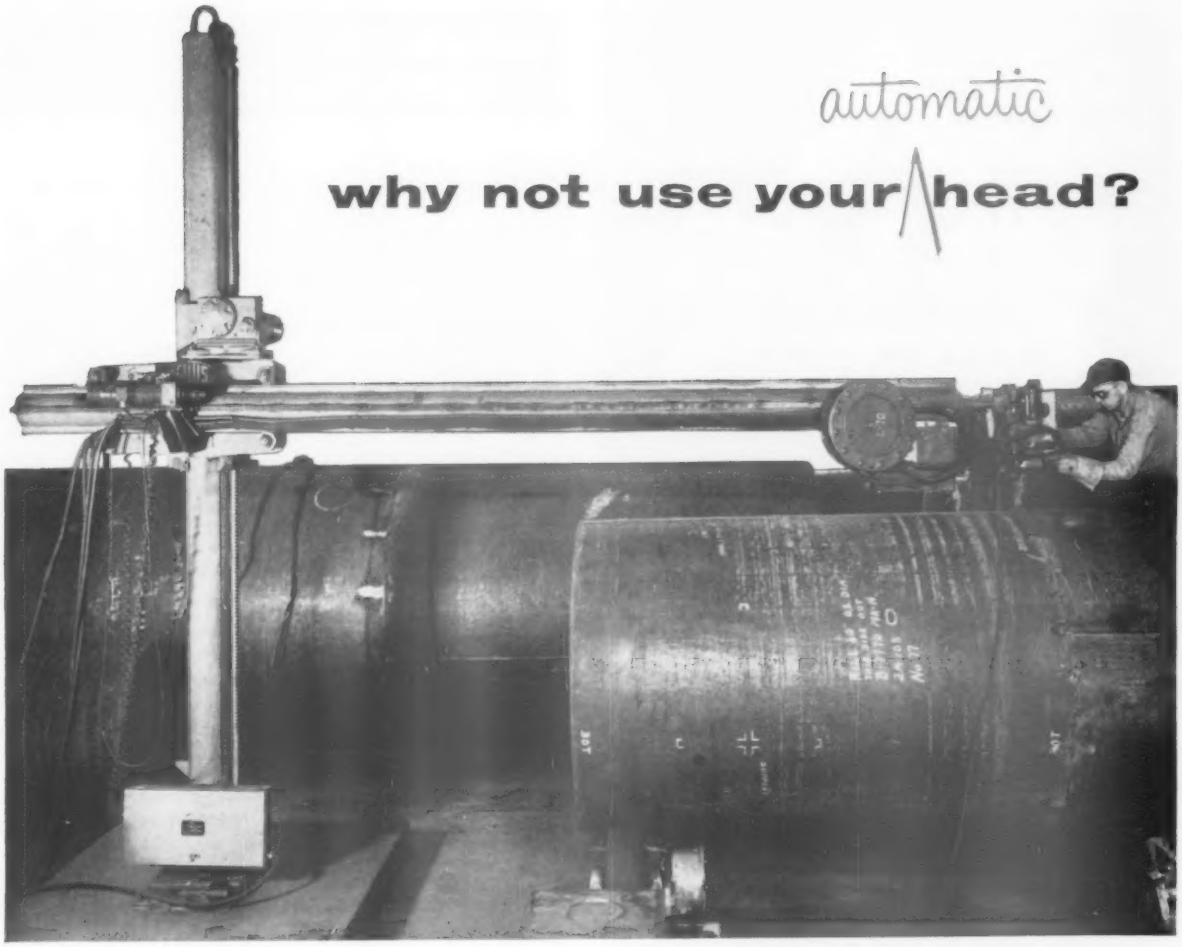
The machine design section presents an entire machine design system which directs the designer from his starting point of "what the machine must do" to a completed design.

The weldability section presents information on how to weld all of the commonly welded metals, including such new materials as zirconium and titanium. The mild-steel welding procedure section gives detailed welding procedures for all joints. These procedures include the new iron-powder manual electrodes, as well as new automatic procedures and the latest information on hard surfacing, carbon arc work, tool and die welding, pipeline, piping and code welding.

Manufacturing cost data includes 28 graphs for estimating the cost of such processes as cutting, forming and welding steel. The charts are for use by designers and production men.

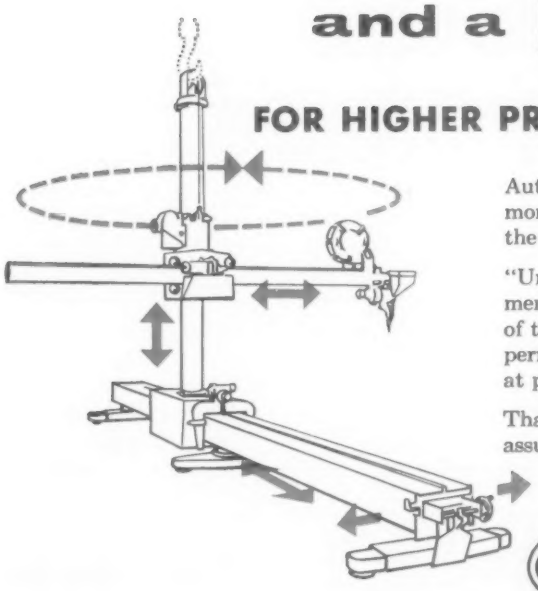
automatic

why not use your head?



and a LEWIS "UNIVERSAL"

FOR HIGHER PROFITS WITH AUTOMATIC WELDING



Automatic welding cuts costs because it is faster, more accurate, more dependable. But . . . the real key to greater savings lies in the automatic welding head manipulator.

"Universal" manipulators, designed and manufactured by a weldment fabricator, are the only *fully portable and adjustable* machines of their type. They can be set-up quickly wherever crane facilities permit . . . position any automatic head rapidly . . . pilot heads at proper welding speeds . . . operate with machine tool accuracy.

That's why LEWIS "Universals", track or pedestal types, assure greater cost savings and profits in automatic welding jobs.

For Details and Prices, write for Bulletin 6960.

LEWIS

THE LEWIS WELDING & ENGINEERING CORP.

WELDING DIVISION

78 INTERSTATE STREET • BEDFORD, OHIO

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SPECIALISTS IN WELDMENT FABRICATION AND PRECISION WELDING EQUIPMENT

HIGH PRODUCTION RESISTANCE WELDING
DELTA
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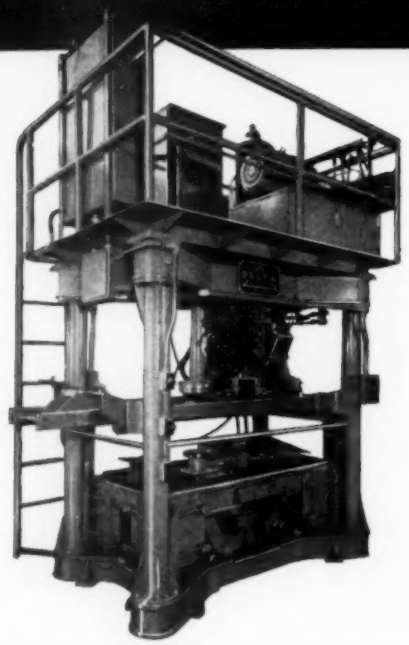

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NOTICE TO ALL MEMBERS

of the American Welding Society, Inc., regarding

AMENDMENTS TO THE BYLAWS

pertaining to membership dues, fees and regulations

In the April 1957 issue of The Welding Journal, pages 386 and 387, "Dues and Grades—A Subject of interest to all AWS Members" was reviewed.

The problems confronting the Society were exhaustively discussed in assemblies, in meetings and by individual groups during our Adams National Meeting at Philadelphia, April 8 through April 12. Presentations were prepared covering the economies of membership, Welding Journal publication and Welding Handbook production. Each received rational and conscientious consideration. Hearings were given to individuals, groups and committees concerned. As should be the case each plan proposed had its strong advocates; each honestly stating his opinion as to the policy he thought would be the best for the overall interests of the Society, its membership and the industry it serves.

The final decision was left with the 1956–57 Board of Directors, whose final meeting convened on Thursday morning, April 11. This session was exceptionally well attended by twenty six (26) of its thirty one (31) members, as well as a large number of the newly elected members of the 1957–58 Board of Directors and invited guest members of prominence in the activities being considered by the convened 1956–57 Board.

All pertinent actions of the 1954–56 and 1956–57 Boards were minutely scrutinized and intently deliberated. All potential effects of actions portending were duly considered.

As a result, after the fundamental issues were completely clarified, a series of actions were moved, duly seconded and voted. The pertinent actions will affect the current bylaws of the Society dealing with membership grades, dues, fees, etc. in the order following:

Student Members:

This grade is not affected.

Honorary Members:

This grade is not affected.

Life Members:

This grade is not affected.

Sustaining Members:

This grade is not affected other than, in conformance with the change in the Society's Constitution as effected on June 8, 1955 at the time of the Society's 36th Annual Business Meeting at Kansas City, the right to hold Sustaining Membership was granted to corporations, firms, partnerships, organizations, associations, etc., in addition to individuals.

Associate Members:

The annual dues of this grade are increased *from* $13.00 *to* $15.00. This increase is in conformance with the economy of the times. There are no reductions in benefits, status or qualifications.

Members:

The annual dues of this grade are increased *from* $18.00 *to* $20.00. This increase is also in conformance with the economy of the times. There are no reductions in benefits, status or qualifications. Each *Member* will continue to receive the Welding Handbook as issued.

Initiation Fee:

An initiation fee of $5.00 shall be instituted upon admission to the grades of Associate Member and Member. Upon entry, each grade shall be given a Membership Certificate suitable for office or home display. This institution does not affect the current membership.

Reinstatement Fee:

A reinstatement fee of $5.00 shall be instituted. This applies to Associate Members and Members

who have been dropped for non-payment of dues. This institution does not affect members in good standing.

Reinstatement:

Associate Members and Members who have been dropped for non-payment of dues shall be eligible for reinstatement only upon payment of the reinstatement fee, and shall not be eligible for admission as a new member. This institution does not affect members who remain in good standing.

Non-Payment of Dues:

The present bylaw allows a member's dues to remain seven (7) months unpaid after his renewal date. The amending action will reduce the period to ninety (90) days instead of two hundred ten (210). Mailing of The Welding Journal shall cease thirty (30) days following his renewal date.

Admission and Enrollment of Members:

A Member shall not be permitted to change from the Member Grade to the Associate Member Grade.

Section Refunds:

In computing the refund to a Section only the annual dues and not the initiation or reinstatement fees shall be considered.

Standing and Special Committee Appointments:

Status is not changed excepting that Chairman of Committees must be a Corporate member of the Society and the President of the Society shall be an ex-officio member of Special Committees.

Special Committees:

Power by bylaw is provided the President, with approval of Board of Directors, to appoint Special Committees for definite stated purpose or purposes.

Committee Reports:

Standing Committees shall submit annual reports and Special Committees interim and final reports to the Board of Directors.

Handbook Committee:

The Welding Handbook Committee is established as a Standing Committee, and its scope is defined.

•

The institution of additional grades of membership such as Junior Member and Fellow grade, was deferred. Consideration has not ceased however. Further studies will be made and such will include studies of other gradations of membership, including the Supporting Company, Sustaining Member and Sponsor pattern. For the time being the changes to be effected are those dictated by the economy of the Society's operations and the needs of the membership and the welding industry.

The bylaws of the Society provide that the membership shall be informed in advance of pending amendments. Such is accomplished in the foregoing announcements. As of June 15, 1957 all members of the Society shall be submitted a letter ballot covering the foregoing, such written in comparative form acquainting the members with the bylaws as presently written and as amended. At this time the amendments are known as "temporary" amendments.

The membership balloting will be closed August 15, 1957. On August 16 the "temporary" amendments shall then be adopted unless rejected by the votes of at least twenty percent (20%) of the eligible voting membership delivered to the Secretary on August 16, 1957.

The Society's Board of Directors and its concerned Committees recommend that the entire membership approve the amendments proposed. Excerpts from the previously mentioned April 1957 Welding Journal article are repeated:

"No person can buy today other than a small portion of what his dollar bought in 1940. The same applies to our SOCIETY. It must purchase all that it buys at the same market price that the individual and the industry must meet. Nevertheless, the SOCIETY has endeavored to maintain its member dues at the lowest possible figure. The fact is that up until 1931 the dues for a Member were $20.00. Each year the SOCIETY spends some $47,000 on its technical activities alone and, in direct return receives but $13,000 for the sale of the tangible items—codes, standards and specifications. However, this is a worth-while investment, because they have contributed notably to the improvement and to the increased use of welding, as well as broadened the knowledge of welding engineering, thereby benefiting every one in the industry.

"The SOCIETY subsidizes the Student membership, giving all Student members THE WELDING JOURNAL each month; the cost of this alone is greater than the student's dues. In the early 1920's the SOCIETY'S membership dues accounted for 90% of its income; today, they account for less than 45%. It must earn the remaining 55%.

"The SOCIETY belongs to you—its members. It can do only what you want and allow it to do. If you wish to accomplish those things vital to you and to your industry, you can provide it with the power to do so. It is your SOCIETY—the answer is yours."

For the American Welding Society, Inc.
J. G. MAGRATH
National Secretary 1947–1957

Welding Research

SPONSORED BY THE WELDING RESEARCH COUNCIL
OF THE ENGINEERING FOUNDATION
W. SPRARAGEN, DIRECTOR

SUPPLEMENT TO THE WELDING JOURNAL, MAY, 1957

SODIUM CORROSION AND OXIDATION RESISTANCE OF HIGH-TEMPERATURE BRAZING ALLOYS

Alloy systems of the Ni-Si-B, Ni-Cr-Si-B and Ni-Cr-Si types found to have excellent resistance to sodium corrosion and oxidation

BY G. M. SLAUGHTER, C. F. LEITTEN, JR., P. PATRIARCA, E. E. HOFFMAN AND W. D. MANLY

INTRODUCTION. The fabrication of heat exchanger equipment for high-temperature service presents exceedingly complex problems, since rigid heat transfer requirements necessitate the use of compact assemblies of thin-walled small-diameter tubes. Intricate designs may also be required in which fins must be securely joined to the tubes at closely spaced intervals.

In addition to the difficulties in fabrication imposed by the designs themselves, the high operating temperatures involved require the careful selection of materials and joining techniques. The choice of fabrication procedure for a given component must be based not only upon the stresses and temperatures to be encountered but also upon other special factors.

The use of liquid-metal coolants, such as sodium for example, requires excellent compatibility of the structural materials with these corrosive media.

Although welding is used extensively in the construction of the extended-surface equipment, high-temperature brazing is

Table 1—Commercial Brazing Alloys

Composition	*Brazing temperature, ° F*
73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C	2050
83.4Ni – 6.0Cr – 5.0Si – 3.0B – 2.5Fe – 0.1C	2000
93.2Ni – 3.5Si – 1.9B – 1.4Fe	2050
91.8Ni – 4.5Si – 2.6B – 1.1Fe	1950
91.2Ni – 4.5Si – 2.9B – 1.4Fe	1900
82.1Ni – 7.0Cr – 4.5Si – 2.9B – 3.5Fe	1880
50.0Ni – 11.8Si – 29.3Fe – 3.5P – 5.4Mo	2050
100Cu	2050

Table 2—Experimental Brazing Alloys

Composition	*Brazing temperature, ° F*	*Composition*	*Brazing temperature, ° F*
87Ni – 13Si	2150	88Ni – 10P – 2Cr	1800
70Ni – 10Si – 20Cr	2150	77Ni – 10P – 13Cr	1850
73Ni – 9Si – 18Cr	2150	81Ni – 11P – 8Mn	1950
54Ni – 10Si – 14Cr – 19Fe – 3Mo	2175	79Ni – 10P – 11Fe	1850
78Ni – 16Si – 6Mn	2175	86Ni – 10P – 4Mo	1850
82Ni – 10Si – 8Mn	2000	80Ni – 11P – 9Si	2050
64Ni – 6Si – 30Mn	1950	89Ni – 5P – 6Si	2000
75Ni – 25Ge	2150	89Ni – 8P – 3Si	1900
65Ni – 25Ge – 10Cr	2100	88Ni – 3P – 9Si	2050
70Ni – 13Ge – 11Cr – 6Si	2080	80Ni – 9P – 11W	2000
50Ni – 25Mo – 25Ge	2150	71Ni – 9P – 15Fe – 5Cr	2100
		64Ag – 33Pd – 3Mn	2150
68Ni – 32Sn	2150	60Pd – 40Ni	2300
40Ni – 60Mn	1950	60Pd – 37Ni – 3Si	2150
35Ni – 55Mn – 10Cr	2050	92Pd – 8Al	2020
38Ni – 57Mn – 5Cr	2000	90Pd – 10Ge	2000
90Ni – 10P	1800	82Au – 18Ni	1830
88Ni – 12P	1800	90Au – 10Co	1830
77Ni – 23P	2100	80Au – 20Cu	1740
80Ni – 10P – 10Cr	1850		

G. M. Slaughter, C. F. Leitten, Jr., P. Patriarca, E. E. Hoffman and W. D. Manly are associated with the Metallurgy Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.

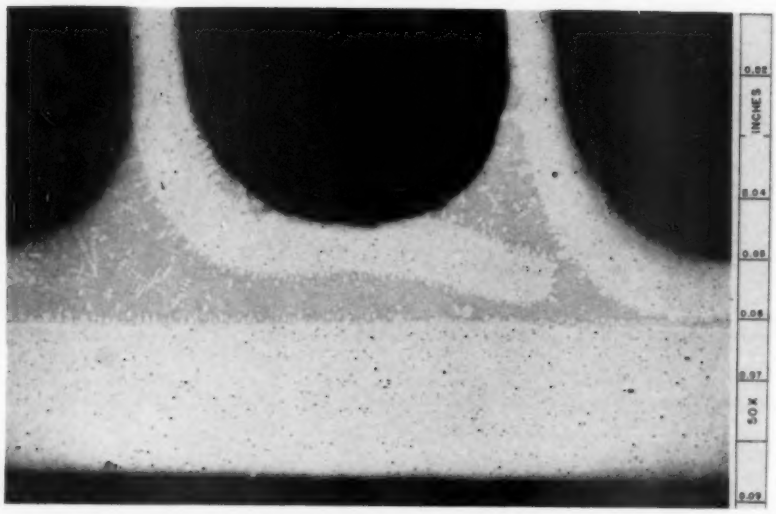

Fig. 1 Photomicrograph of a section of a brazed tube-to-fin joint. Etch: None. X 50. (Reduced by one-third upon reproduction)

also attractive for several applications. Typical of the joints desired is that shown in Fig. 1 in which stainless steel fins are brazed to an Inconel tube. High-temperature brazing is also advantageous as a means of reinforcing tube-to-header welds. In Fig. 2, a photomicrograph of a typical back-brazed tube-to-header weld, it can be seen that only partial weld penetration was obtained. The brazed joint eliminates the notch effect and assists in the prevention of serious leaks in the system if corrosion through localized areas of shallow weld penetration occurs during service.

A long-range brazing-alloy development and evaluation program has therefore been in progress in the Metallurgy Division of the Oak Ridge National Laboratory (ORNL) for several years to obtain fundamental information regarding the feasibility of using brazing alloys in high-temperature heat exchanger applications. Numerous commercially available brazing alloys have been extensively investigated, as have many more alloys developed at ORNL and other laboratories. Listings of the alloys and their brazing temperatures are presented in Tables 1 and 2. Initial tests, which are performed by the Welding and Brazing Group, permit a determination of the general over-all suitabilities of the alloys for high-temperature, dry-hydrogen (flux-free) brazing. These tests include preliminary studies of such properties as flow point, flowability and ductility. The Welding and Brazing Group also conducts high-temperature oxidation tests on brazed joints and, in general, correlates information and test results obtained from other groups in the Metallurgy Division and from certain outside sources. Corrosion studies on these alloys have been under the direction of the General Corrosion Group, and limited physical-property tests have been conducted by the Physical Testing Group. This paper, however, covers only the results of the high-temperature sodium corrosion and oxidation testing programs. Comments on the other phases of investigation are added only where they are pertinent to the subject under discussion.

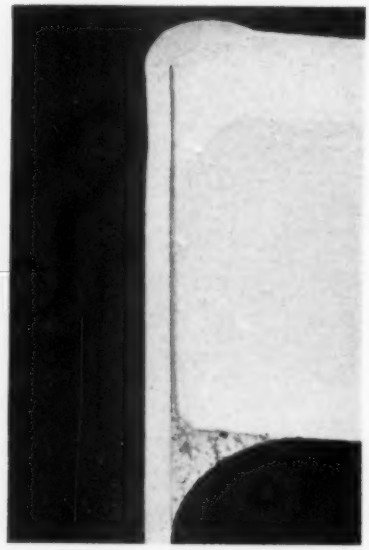

Fig. 2. Photomicrograph of a typical back-brazed tube-to-header weld. Etch: Electrolytic oxalic acid. X 12. (Reduced by one-half upon reproduction)

As a result of these investigations and evaluations, it is possible to suggest logical brazing alloys for specific applications. In some cases, excellent resistance of the brazing alloy to high-temperature oxidation is a requisite, while in others good compatibility with liquid sodium is essential. The extent of corrosion and oxidation upon many potential high-temperature brazing alloys is presented in tabular form in this paper, and several promising alloys are listed. High-magnification photomicrographs showing the resistance to attack of many of these alloys are included to permit a visual analysis.

It should be emphasized that this paper is not a complete résumé of research conducted at ORNL on brazing alloys. A continuing program of alloy development and evaluation is being conducted in the hope of finding materials possessing more suitable combinations of environmental compatibility, flowability, ductility and high-temperature strength.

Aspects of Brazing-Alloy Development

Brazing alloys containing nickel as the base metal are of primary interest for use in heat exhanger applications for high-temperature, high-corrosion service. Nickel is compatible with static sodium at temperatures in the range of 1500–1700° F; however, it does suffer to a slight extent from mass transfer in dynamic nonisothermal sodium systems at 1500° F and above. Its resistance to oxidation at these temperatures is also promising and can be made exceptional with slight additions of some alloying elements. Nickel is very malleable in its pure form, thereby presenting a good starting point for the production of alloys containing an inherent degree of ductility.

The melting point of nickel is 2650° F, but brazing alloys for use in ordinary high-temperature applications utilizing Inconel or the stainless steels should melt below 2200° F to minimize distortion and grain growth in the structural materials. Fortunately, however, certain elements, when alloyed with nickel in small quantities, cause rapid reductions in melting point. Some elements, such as boron, form binary eutectics with nickel, and the phase diagram of this system is shown in Fig. 3. Other elements of interest which form alloys of a similar type are phosphorus, silicon, germanium and tin. Complex brazing-alloy compositions containing various percentages of each component can be prepared, and the melting points vary accordingly. However, it can be assumed for most cases that ternary or quaternary eutectics possess lower melting points than any of the binary eutectics. Each alloy composition also possesses unique physical and chemical properties, although

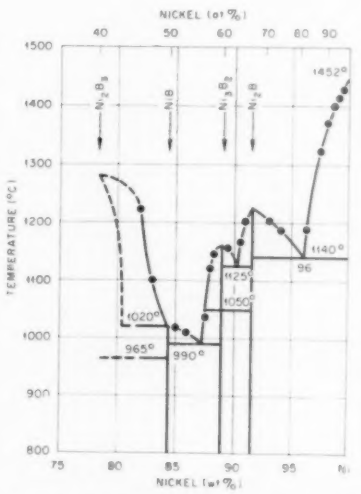

Fig. 3 Nickel-boron equilibrium phase diagram

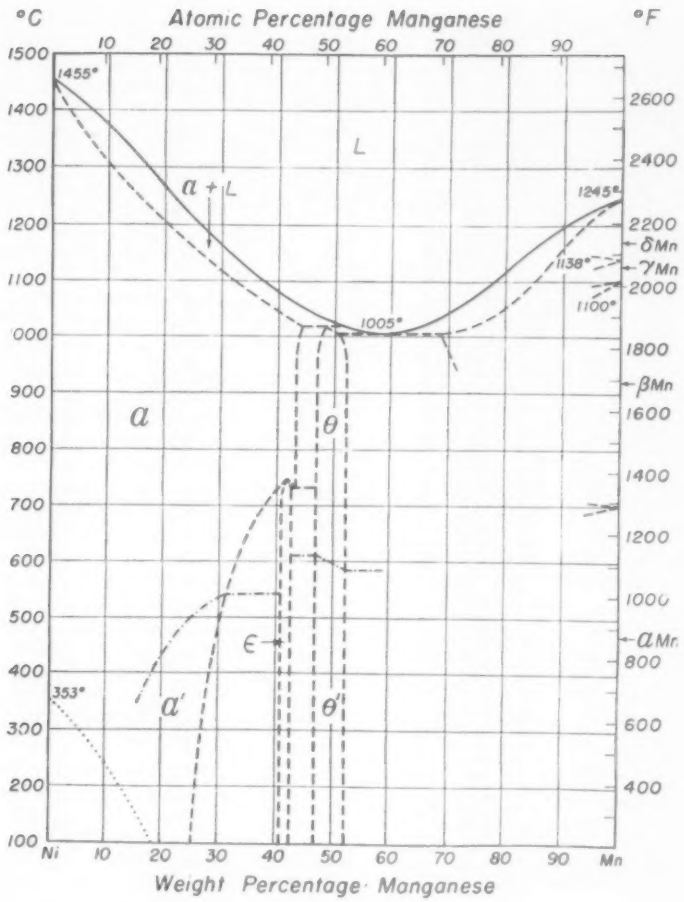

Fig. 4 Nickel-manganese equilibrium phase diagram

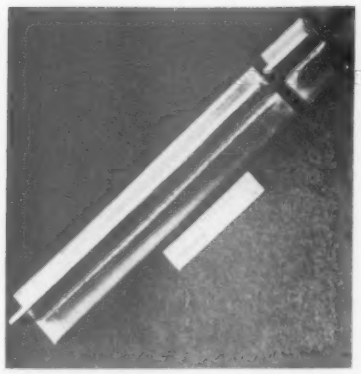

Fig. 5 Photograph of a brazed T-joint which had been prepared by placing a controlled quantity of brazing alloy at one end and heating to the flow point in a dry-hydrogen atmosphere

melting point can be reduced by a judicious choice of samples.

This paper presents a summary of the resistance to corrosion and oxidation of many alloy systems which have been investigated and developed both commercially and by various research organizations. Systems which were promising from these standpoints were studied extensively, while alloy systems exhibiting less use for high-temperature applications were studied only slightly. However, continuing research on nickel-base alloys is being conducted, including development programs on alloys for applications involving other corrosive environments.

certain trends may be followed. For example, the presence of phosphorus in nickel-base brazing alloys has been found to reduce the joint ductility in all cases which have been tested.

Other alloy systems which are of interest contain a minimum in the liquidus-solidus lines of their phase diagrams. Typical of these systems is nickel-manganese, and its constitution diagram is shown in Fig. 4. The nickel-gold and nickel-palladium systems also possess complete solid solubility in all proportions. Alloys of these systems generally are quite ductile.

The development of brazing alloys for high-temperature, high-corrosion service must necessarily be based upon phase-diagram analyses. With the aid of a systematic study of the melting point and flowability of alloy systems over wide variations of chemical composition, it is frequently possible to determine the presence of particular compositions having desirable characteristics for brazing. Although such investigations are time-consuming, the number of sample melts required to determine the composition of lowest

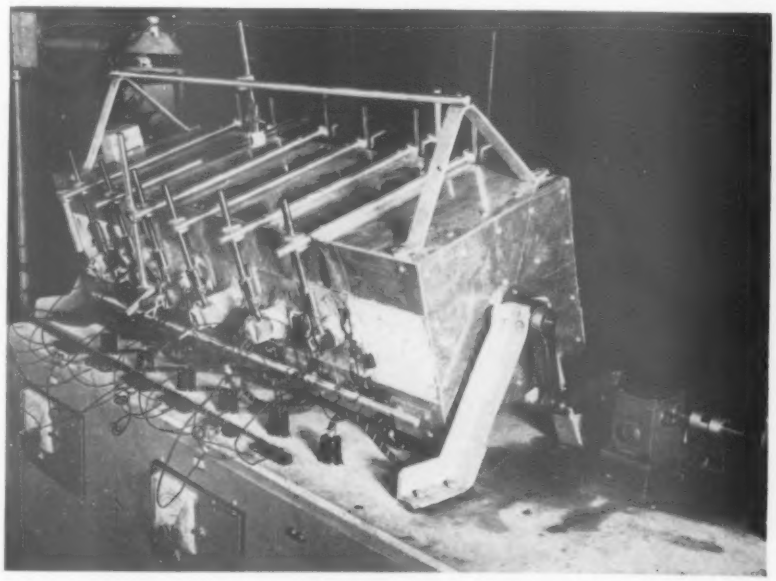

Fig. 6 Photograph of the "seesaw" furnace used in the dynamic testing of brazing alloys

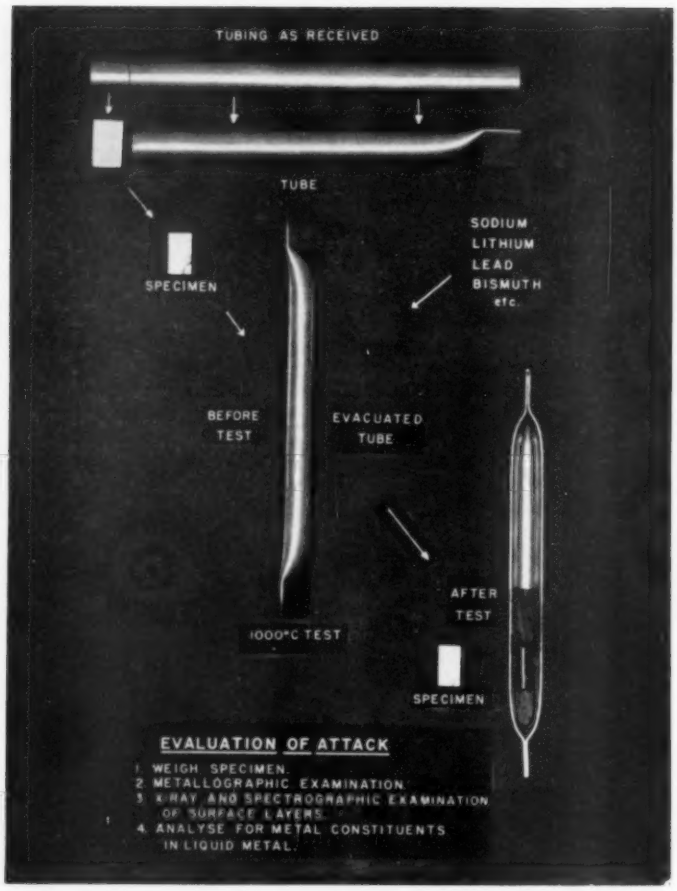

Fig. 7 Photograph which schematically represents the loading procedure for the "seesaw" and static corrosion test

Brazing Equipment and Preparation of Specimen

The process of dry-hydrogen brazing has become of recognized importance in recent years as a means of component fabrication for high-temperature, corrosion-resistant service. Flux entrapment, with its consequent deleterious effects in certain applications, is eliminated, and exceedingly high-quality brazed joints can be produced. The hydrogen chemically reduces the metallic oxides to the pure metals and promotes the formation of a scale-free surface. As a result, common high-temperature structural materials such as Inconel and the stainless steels are easily wet by most brazing alloys.

A hydrogen dew pont lower than -70° F is recommended for the brazing of these materials to permit satisfactory flowability. To obtain this high quality from the saturated hydrogen which may be present in the as-received bottled gas, an elaborate drying and purification train is required. Since very high flow rates may be needed for many operations, purifiers possessing a high effective capacity should be used throughout.

In this investigation, the removal of residual oxygen from the hydrogen was performed by a commercially available palladium catalyst. This oxygen combines with the hydrogen to form water vapor. An activated alumina drying unit absorbed this water, along with the water vapor originally present in the tank hydrogen, and was adequate to reduce the hydrogen dew point to −120° F or lower. Additional purification equipment in use in the Welding and Brazing Laboratory consisted of a hot titanium sponge scavenger.

A Globar-heated furnace containing a 2-in.-diam Inconel muffle was used for brazing the specimens to be used in the corrosion and oxidation tests. A water-cooled chamber facilitated cooling to room temperature. Accurate temperature measurement and control was made possible by a platinum, platinum-rhodium thermocouple enclosed in an impervious ceramic tube.

T-joints, similar to the one shown in Fig. 5, were brazed by placing controlled quantities of brazing alloy on

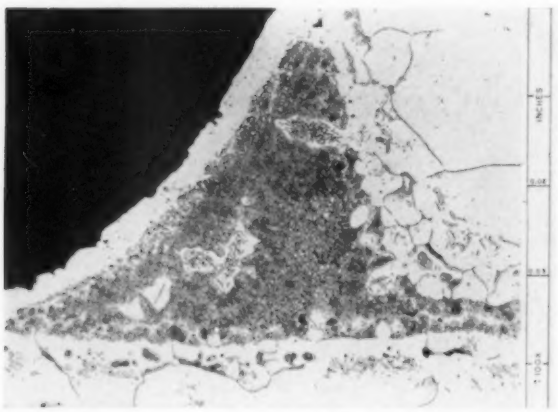

Fig. 8 Photomicrograph of a T-joint brazed with 91.2Ni – 4.5Si – 2.9B – 1.4Fe alloy after testing in sodium for 100 hr at 1500° F

Good resistance to attack is evident. Etch: Oxalic acid (electrolytic). X 100. (Reduced by one-half upon reproduction.)

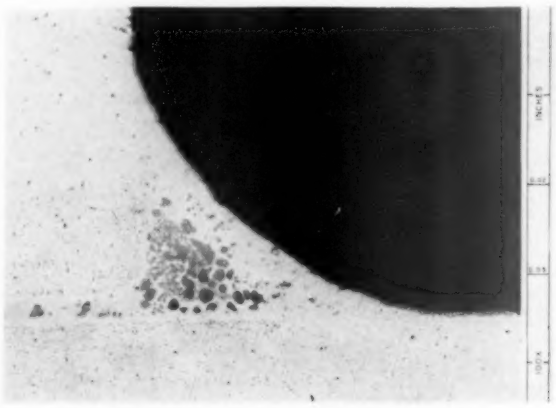

Fig. 9 Photomicrograph of a T-joint brazed with 91.2Ni – 4.5Si – 2.9B – 1.4Fe alloy after testing in air for 500 hr at 1500° F

Negligible attack can be seen. Etch: Oxalic acid (electrolytic). X 100. (Reduced by one-half upon reproduction.)

Table 3—Results of Static Tests of Brazing Alloys on "A" Nickel T-Joints in Sodium at 1500° F for 100 Hr*

Brazing alloy composition wt-%	*Weight change†* g	%	*Metallographic notes*
70Ni – 10Si – 20Cr	+0.0001	+0.005	No attack on braze fillet.
91.2Ni – 4.5Si – 2.9B – 1.4Fe	−0.0019	−0.068	0.5-mil surface attack along fillet edge.
80Ni – 10P – 10Cr	−0.0017	−0.061	1-mil nonuniform attack along fillet.
73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C	−0.0022	−0.082	1.5-mil layer of small subsurface voids along fillet edge
75Ni – 25Ge	0.0	0.0	2-mil nonuniform attack along surface of braze fillet.
50Ni – 25Mo – 25Ge	−0.0009	−0.036	2.5-mil attack along surface of fillet.
65Ni – 25Ge – 10Cr	−0.0024	−0.085	3-mil uniform surface attack along fillet.
40Ni – 60Mn	−0.0020	−0.079	9-mil uniform attack along entire fillet.
35Ni – 55Mn – 10Cr	−0.0005	−0.020	13 mils of small voids in from surface of fillet.
68Ni – 32Sn	−0.0171	−0.540	Complete attack of whole fillet.

* Brazing alloys listed in order of decreasing corrosion resistance to sodium.
† Weight change data for brazing alloys and base material of joint.

one end of the specimens. The alloy, upon melting, flowed evenly along the joint. All specimens were held at the brazing temperature for approximately 10 min. Several small corrosion samples could then be taken from this one specimen as described in the next section.

Testing Procedure

A. Corrosion

In the corrosion testing of brazing alloys in various heat exchanger media, two testing techniques are now employed—the "static" and the "seesaw." The static method is far more simple than the seesaw method and serves as a rapid means for screening large numbers of brazing alloys in various heat transfer media. The seesaw method, on the other hand, is a dynamic corrosion test in which the testing medium is not stagnant with respect to the sample being tested, as it is in the static test. In the seesaw technique, the movement of the corrosive liquid is obtained by the oscillation of the furnace. Figure 6 is a photograph of the "seesaw" furnace which was used in the dynamic testing of the brazed samples. The rocking speed used in the brazing-alloy seesaw tests was chosen as 4.25 cpm. With this equipment, the effect of a thermal gradient in the circulating bath on the corrosion resistance of the test sample can also be observed. Since the test capsule is positioned in such a manner that only a portion of it is in the hot zone of the furnace, a desired temperature differential can be obtained by regulating the distance that the capsule extends out from the hot zone. In general, it has been found that brazing alloys which were attacked during the static test were more severely attacked during the seesaw test.

Table 4—Results of Static Tests of Experimental Brazing Alloys on Types 304 and 310 Stainless Steels in Sodium at 1500° F for 100 Hr*

Brazing alloy composition, wt-%	*Base material*	*Weight change†* g	%	*Metallographic notes*
73Ni – 9Si – 18Cr	304 SS	0.0	0.0	No attack along surface of braze fillet.
88Ni – 3P – 9Si	310 SS	0.0	0.0	No attack along surface of fillet.
82Ni – 10Si – 8Mn	310 SS	−0.0002	−0.018	No attack along fillet.
78Ni – 16Si – 6Mn	310 SS	0.0004	0.043	No evidence of attack.
87Ni – 13Si	304 SS	−0.0007	−0.068	Surface of braze fillet unattacked.
77Ni – 10P – 13Cr	304 SS	0.0004	0.054	Less than 0.5 mils of small subsurface voids.
64Ni – 6Si – 30Mn	310 SS	−0.0002	−0.022	1 mil erratic surface attack.
80Ni – 9P – 11W	310 SS	−0.0002	−0.019	2.5-mil uniform attack along the surface of the braze fillet
54Ni – 10Si – 14Cr – 19Fe – 3Mo	310 SS	0.0	0.0	Subsurface voids to a depth of 3 mils along fillet.
89Ni – 5P – 6Si	310 SS	0.0	0.0	Maximum attack of 4 mils along surface of fillet.
80Ni – 11 – P – 9Si	304 SS	0.0	0.0	Subsurface voids to a depth of 4 mils along fillet.
89Ni – 8P – 3Si	310 SS	−0.0012	−0.14	Maximum attack of 4 mils along surface of braze fillet.
38Ni – 57Mn – 5Cr	310 SS	−0.0004	−0.043	Attack in the form of stringers to a maximum depth of 5 mils, not uniform.

* Brazing alloys listed in order of decreasing corrosion resistance to sodium.
† Weight change data for brazing alloys and base material of joint.

The corrosion tests were performed on dry-hydrogen-brazed T-joints. The over-all length of each T-joint was approximately 3 in., and $\frac{1}{2}$-in. sections were cut from the T-joints for corrosion testing. Each section was thoroughly cleaned in acetone and weighed on a Gram-atic balance before being placed in the container tube.

To minimize the existence of compositional gradients which can cause variations in corrosive attack through a mechanism of dissimilar-metal mass transfer, it was desirable to select a container material of the same composition as the base material of the brazed T-joint. In all these brazing-alloy tests, this precaution was utilized.

The loading procedure used in the static and seesaw corrosion tests is schematically shown in Fig. 7. The brazed T-joint, represented in this figure by the small square specimen, is placed in a tube which has been crimped and welded at one end. A partial crimp is then applied to the tube wall in order to retain the specimen in the crimped section. In such a procedure, the bath can be removed from the test sample upon completion of the test by merely inverting the partially filled test container. This crimping practice also serves to hold the test sample in the hot zone during seesaw testing. The testing medium is loaded into the container tube in an inert-atmosphere dry box. This apparatus facilitates the handling of liquid metals without serious contamination from the atmosphere. The tubes are then evacuated and sealed by crimping and welding.

Upon completion of the test, the capsules are sectioned for visual examination of bath, container and test specimen. A sample of the bath is usually removed for chemical analysis. The tested brazed T-joints are then thoroughly cleaned and again weighed on a Gram-atic balance in order to determine the weight change during testing. Although this weight change is not limited to the brazing alloy but also includes that of the T-joint base metal, the data are very useful in cases where a uniform solution attack has occurred on the brazing alloy. This type of attack is not readily discernible in a metallographic examination and can easily be overlooked. The final and most important stage in the exam-

ination of the tested T-joints is the metallographic examination. Before each T-joint is examined metallographically, an electrodeposited nickel plate is applied to prevent the rounding-over of the brazed fillet edges during the polishing procedure. An as-brazed T-joint is likewise plated and examined to determine the fillet contour and the degree of porosity present before corrosion testing. This procedure acts as a guide in evaluating the corrosion results.

The results of these tests can then be compiled in tabular form and general observations made. From an inspection of these tables, it is possible to suggest brazing alloys for use in various heat exchanger applications. It should, however, be emphasized that these results serve only as a guide, and more comprehensive tests must be conducted under conditions similar to those expected in actual service.

Table 5—Brazing Alloys on Inconel T-Joints Seesaw Tested in Sodium for 100 Hr at a Hot-Zone Temperature of 1500° F*

Brazing Alloy composition, wt-%	*Weight Change* g†	%	*Metallographic notes*
91.2Ni – 4.5Si – 2.9B – 1.4 Fe	−0.0011	−0.073	No attack along surface of braze fillet.
82.1Ni – 7.0Cr – 4.5Si – 2.9B – 3.5Fe	−0.0009	−0.071	1-mil erratic attack along surface of braze fillet.
83.4Ni – 6.0Cr – 5.0Si – 3.0B – 2.5Fe – 0.1C	−0.0007	−0.051	Subsurface voids to a maximum depth of 1.5 mils along surface of braze fillet.
93.2Ni – 3.5Si – 1.9B – 1.4 Fe	−0.0012	−0.077	1.5-mil very erratic surface attack along fillet.
70Ni – 13Ge – 11Cr – 6Si	−0.0023	−0.139	Nonuniform attack along surface of braze fillet to a depth of 2.5 mils.
50.0Ni – 11.8Si – 29.3Fe – 3.5P – 5.4Mo	−0.0069	−0.622	2.5-mil uniform attack along surface of braze fillet.
70Ni – 10Si – 20Cr	−0.0018	−0.163	3-mil uniform surface attack along braze fillet.
73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C	0.0	0.0	Very erratic stringer attack to a maximum depth of 4 mils along surface of braze fillet.
65Ni – 25Ge – 10Cr	−0.0019	−0.113	Intermittent surface attack to a maximum depth of 4 mils along braze fillet.

* Brazing alloys listed in order of decreasing corrosion resistance to sodium.
† Weight change data for brazing alloys and base material of joint.

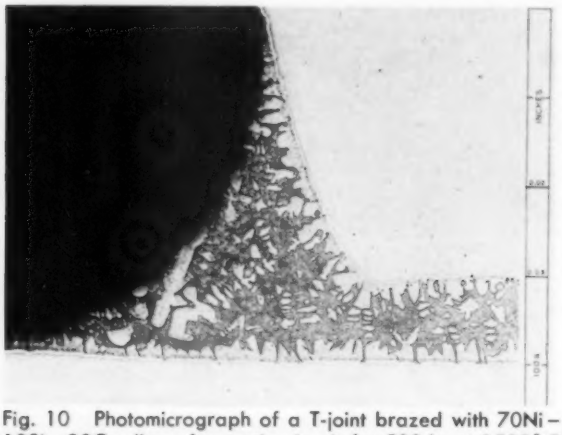

Fig. 10 Photomicrograph of a T-joint brazed with 70Ni – 10Si – 20Cr alloy after testing in air for 500 hr at 1500° F

Excellent resistance to attack is evident. Etch: None. X 100. (Reduced by one-half upon reproduction.)

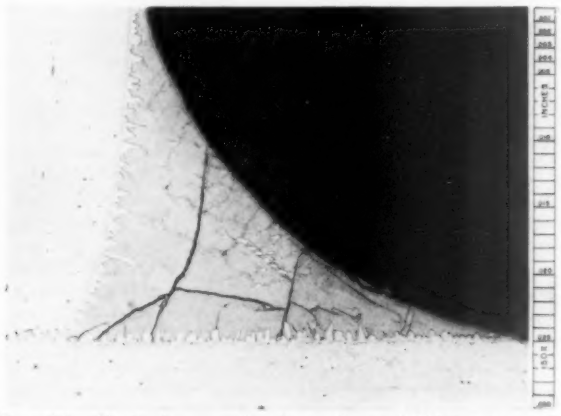

Fig. 11 Photomicrograph of an Inconel T-joint brazed with 88Ni – 12P in the as-brazed condition

Note the cracks which are present in the braze fillet. Etch: Oxalic acid. X 150. (Reduced by one-half upon reproduction.)

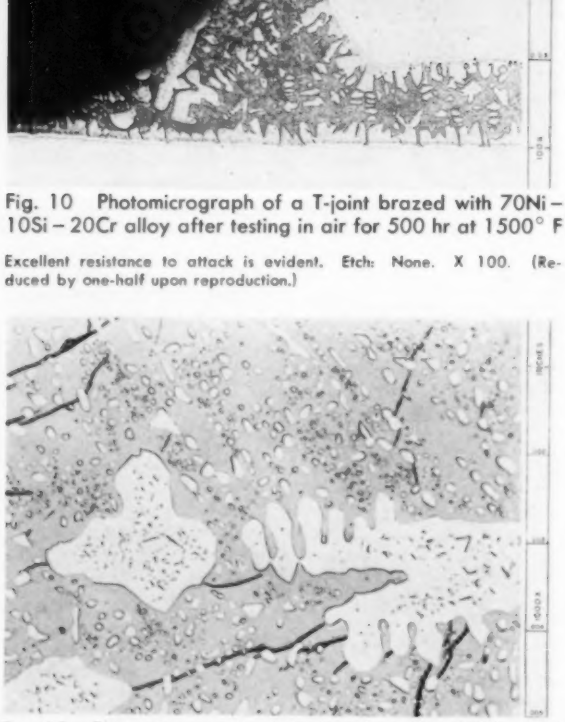

Fig. 12 Photomicrograph of the brazing alloy 88Ni – 12P at high magnification

Note the cracks which occurred in the brittle Ni_3P phase. Etch: Oxalic acid. X 1000. (Reduced by one-half upon reproduction.)

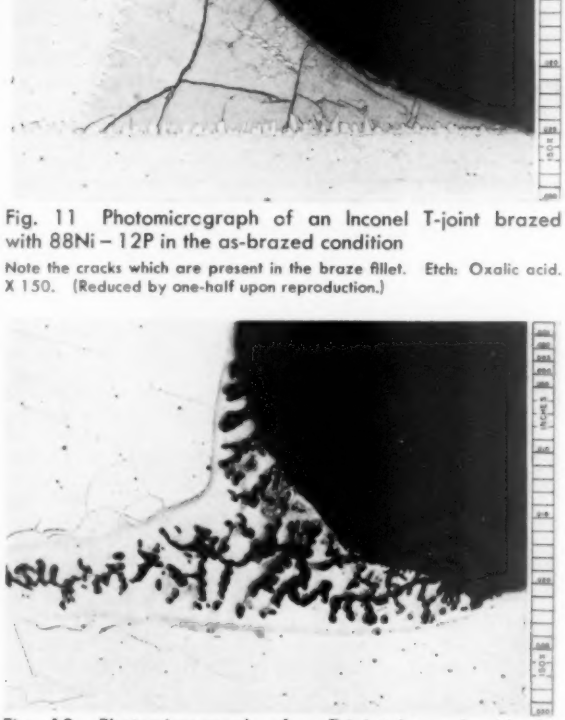

Fig. 13 Photomicrograph of a T-joint brazed with the 60Pd – 37Ni – 3Si alloy after static testing for 100 hr at 1500° F in sodium

Note the extensive attack in the braze fillet. Etch: G. Regia. X 150. (Reduced by one-half upon reproduction.)

B. Oxidation

The oxidation resistance of high-temperature brazing alloys was determined from tests conducted on small samples taken from brazed T-joints similar to those used in corrosion testing. A resistance-wound box-type furnace, possessing a hot zone approximately 5 x 8 x 14 in., was utilized in this study. No circulation of air was maintained in the furnace other than that arising from natural convection.

Samples were tested both statically and with intermittent cycling to room temperature from the testing temperature. The cyclic testing was performed to observe the effects which might be encountered from the spalling of a protective oxide film during thermal fluctuations in service.

In these oxidation studies, the influence of several variables upon the extent of attack on the alloys was evaluated. Samples were held statically for different times at the testing temperatures to permit a relative measure of the rate of oxidation. Two different testing temperatures, 1500 and 1700° F, were also investigated to determine the influence of temperature upon the extent of oxidation over the intended service temperature range. Cyclic testing was performed for 500 hr on many alloys at both temperatures.

The extent and type of oxidation was determined from a metallographic evaluation of the brazed T-joints after testing. The influence of the different testing variables was studied, and the results are summarized in tabular form. As alloys of widely differing chemical compositions were investigated, a general knowledge of the influence of certain alloying additions upon the oxidation resistance can also be obtained.

Results

Table 3 indicates the results of the static corrosion tests in sodium of several brazing alloys under study at ORNL. These tests were conducted for 100 hr at a temperature of 1500° F. Since previous corrosion studies on the precious metals in sodium indicated their poor corrosion resistance, no brazing alloy containing a precious metal as a constituent was tested.

The results of the static tests in sodium for some additional experimental brazing alloys submitted for corrosion studies are listed in Table 4.

Table 5 shows the results obtained in seesaw tests in which sodium was circulated for 100 hr at a hot-zone temperature of 1500° F. The temperature differential, approximately 400° F, was fairly constant for all the seesaw tests. Since these tests provide a more rigorous means of evaluating corrosion data, no brazing alloy which had poor corrosion resistance to sodium in the

Table 6—Oxidation Resistance of Dry-Hydrogen-Brazed Inconel T-Joints*

	Oxidation in static air†				
	At 1500° F			At 1700° F	
Brazing alloy	*200 hr*	*500 hr*	*1300 hr*	*200 hr*	*500 hr*
92Pd – 8Al	Very slight	Very slight	Very slight	Very slight	Slight
73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C	Slight	Slight	Slight	Slight	Slight
83.4Ni – 6.0Cr – 5.0Si – 3.0B – 2.5Fe – 0.1C	Slight	Slight	Slight	Slight	Slight
93.2Ni – 3.5Si – 1.9B – 1.4Fe	Slight	Slight	Slight	Slight	Slight
91.8Ni – 4.5Si – 2.6B – 1.1Fe	Slight	Slight	Slight	Slight	Slight
91.2Ni – 4.5Si – 2.9B – 1.4Fe	Slight	Slight	Slight	Slight	Slight
82.1Ni – 7.0Cr – 4.5Si – 2.9B – 3.5Fe	Slight	Slight	Slight	Slight	Slight
50.0Ni – 11.8Si – 29.3Fe – 3.5P – 5.4Mo	Slight	Slight	Slight	Slight	Moderate
70Ni – 10Si – 20Cr	Slight	Slight	Slight	Slight	Moderate
65Ni – 25Ge – 10Cr	Slight	Slight	Slight	Slight	Moderate
70Ni – 13Ge – 11Cr – 6Si	Slight	Slight	Slight	Slight	Moderate
60Pd – 40Ni	Very slight	Slight	Moderate	Very slight	Slight
90Ni – 10P	Slight	Slight	Slight	Above MP of alloy	...
80Ni – 10P – 10Cr	Slight	Slight	Slight	Above solidus of alloy	...
60Pd – 37Ni – 3Si	Very slight	Slight	Moderate	Slight	Moderate
82Au – 18Ni	Very slight	Very slight	Slight	Moderate	Moderate
75Ni – 25Ge	Slight	Slight	Slight	Moderate	Severe
50Ni – 25Mo – 25Ge	Slight	Slight	Slight	Moderate	Moderate
90Au – 10Co	Very slight	Very slight	Moderate	Slight	Severe
90Pd – 10Ge	Very slight	Slight	Severe	Complete	...
68Ni – 32Sn	Slight	Moderate	Severe	Severe	Complete
64Ag – 33Pd – 3Mn	Severe	Severe	Severe	Complete	...
35Ni – 55Mn – 10Cr	Severe	Severe	Complete	Severe	Complete
80Au – 20Cu	Moderate	Complete	...	Complete	...
40Ni – 60Mn	Complete	...	...	Complete	...
Copper	Complete	...	...	Complete	...

* Alloys are listed in order of decreasing oxidation resistance.

† Very slight, less than 1 mil penetration. Slight, 1 to 2 mils of penetration. Moderate, 2 to 5 mils of penetration. Severe, greater than 5 mils of penetration. Complete fillet completely destroyed.

Table 7—Oxidation Resistance of Inconel T-Joints Dry-Hydrogen Brazed with Some Special Alloys (Testing Temperature 1500° F)

Alloy	*Oxidation after 500 hr (static air)**	*Oxidation after 500 hr (cyclic testing with 190 air cools to room temperature)**	*Oxidation after 1300 hr (static air)**
Inconel base material			
88Ni – 12P	Slight	Moderate	Slight
80Ni – 11P – 9Si	Slight	Slight	Moderate
86Ni – 10P – 4Mo	Slight	Slight	Moderate
81Ni – 11P – 8Mn	Moderate	Moderate	Moderate
Type 304 SS base material			
77Ni – 10P – 13Cr	Slight	Slight	Slight
77Ni – 23P	Slight	Slight	Moderate
88Ni – 10P – 2Cr	Slight	Slight	Moderate
71Ni – 9P – 15Fe – 5Cr	Slight	Slight	Severe
79Ni – 10P – 11Fe	Slight	Moderate	Severe

* Very slight, less than 1 mil penetration. Slight 1 to 2 mils of penetration. Moderate, 2 to 5 mils of penetration. Severe, greater than 5 mils of penetration. Complete, fillet completely destroyed.

Table 8—Oxidation Resistance of Dry-Hydrogen-Brazed Inconel T-Joints at 1500° F for 500 Hr*

Brazing alloy	*Oxidation in static air†*	*Oxidation with 190 air cools to room temperature**
82Au – 18Ni	Very slight	Slight
90Au – 10Co	Very slight	Slight
73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C	Slight	Slight
83.4Ni – 6.0Cr – 5.0Si – 3.0B – 2.5Fe – 0.1C	Slight	Slight
93.2Ni – 3.5Si – 1.9B – 1.4Fe	Slight	Slight
82.1Ni – 7.0Cr – 4.5Si – 2.9B – 3.5Fe	Slight	Slight
50.0Ni – 11.8Si – 29.3Fe – 3.5P – 5.4Mo	Slight	Slight
70Ni – 10Si – 20Cr	Slight	Slight
75Ni – 25Ge	Slight	Slight
65Ni – 25Ge – 10Cr	Slight	Slight
70Ni – 13Ge – 10Cr – 6Si	Slight	Slight
50Ni – 25Mo – 25Ge	Slight	Slight
80Ni – 10P – 10Cr	Slight	Slight
60Pd – 37Ni – 3Si	Slight	Slight
92Pd – 8Al	Very slight	Moderate
91.8Ni – 4.5Si – 2.6B – 1.1Fe	Slight	Moderate
91.2Ni – 4.5Si – 2.9B – 1.4Fe	Slight	Moderate
90Ni – 10P	Slight	Moderate
90Pd – 10Ge	Slight	Severe
68Ni – 32Sn	Moderate	Severe
35Ni – 55Mn – 10Cr	Severe	Severe
64Ag – 33Pd – 3Mn	Severe	Severe
Copper	Complete	Complete
40Ni – 60Mn	Complete	Complete
80Au – 20Cu	Complete	Complete

* Alloys are listed in order of decreasing oxidation resistance.
† Very slight, less than 1 mil penetration. Slight, 1 to 2 mils of penetration. Moderate, 2 to 5 mils of penetration. Severe, greater than 5 mils of penetration. Complete, fillet completely destroyed.

Table 9—Oxidation Resistance of Dry-Hydrogen-Brazed Inconel T Joints at 1700° F* for 500 Hr*

Brazing alloys	*Oxidation in static air†*	*Oxidation with 220 air cools to room temperature†*
73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C	Slight	Slight
82.1Ni – 7.0Cr – 4.5Si – 2.9B – 3.5Fe	Slight	Slight
83.4Ni – 6.0Cr – 5.0Si – 3.0B – 2.5Fe – 0.1C	Slight	Moderate
93.2Ni – 3.5Si – 1.9B – 1.4Fe	Slight	Moderate
60Pd – 40Ni	Slight	Moderate
92Pd – 8Al	Slight	Moderate
91.8Ni – 4.5Si – 2.6B – 1.1Fe	Slight	Severe
91.2Ni – 4.5Si – 2.9B – 1.4Fe	Slight	Severe
50.0Ni – 11.8Si – 29.3Fe – 3.5P – 5.4Mo	Moderate	Moderate
70Ni – 10Si – 20Cr	Moderate	Moderate
75Ni – 25Ge	Moderate	Moderate
65Ni – 25Ge – 10Cr	Moderate	Moderate
50Ni – 25Mo – 25Ge	Moderate	Moderate
82Au – 18Ni	Moderate	Severe
90Au – 10Co	Severe	Severe
90Pd – 10Ge	Complete	Complete
68Ni – 32Sn	Complete	Complete
64Ag – 33Pd – 3Mn	Complete	Complete
40Ni – 60Mn	Complete	Complete
35Ni – 55Mn – 10Cr	Complete	Complete
80Au – 20Cu	Complete	Complete
40Ni – 60Mn	Complete	Complete
Copper	Complete	Complete

* Alloys are listed in order of decreasing oxidation resistance.
† Very slight, less than 1 mil penetration. Slight, 1 to 2 mils of penetration. Moderate, 2 to 5 mils of penetration. Severe, greater than 5 mils of penetration. Complete, fillet completely destroyed.

static test was seesaw-tested. However, a few alloys were investigated which were similar in composition to ones having adequate resistance in the static test.

Tables 6 through 9 present the results of the high-temperature oxidation tests on several brazing alloys. Table 6 presents a summary of the static oxidation resistance of several alloys at 1500 and 1700° F for times up to 1300 hr, while Tables 8 and 9 compare the resistance to static and cyclic attack at 1500 and 1700° F, respectively. Table 7 contains data on the oxidation resistance of some of the other experimental alloys at 1500° F.

Evaluation of Alloys

It can be seen, from an analysis of the previously mentioned tables, that a wide variety of brazing alloys possess adequate sodium corrosion or oxidation resistance. Several alloys exhibited good resistance to attack by both media, and the most promising are listed below:

1. 91.2Ni – 4.5Si – 2.9B – 1.4Fe
2. 82.1Ni – 7.0Cr – 4.5Si – 2.9B – 3.5Fe
3. 83.4Ni – 6.0Cr – 5.0Si – 3.0B – 2.5Fe – 0.1C
4. 70Ni – 10Si – 20Cr
5. 80Ni – 10Cr – 10P
6. 93.2Ni – 3.5Si – 1.9B – 1.4Fe
7. 73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C

The nickel-silicon-boron-iron alloy, No. 1 above, was one of the alloys which exhibited resistance to both corrosion and oxidation. Figures 8 and 9 are photomicrographs of brazed T-joints after testing in these media at 1500° F for 100 and 500 hr, respectively. Alloys Nos. 2, 3, 6 and 7 above are other boron-containing alloys possessing good compatibility in both environments.

Alloys of the Ni-Cr-Si type also possess good corrosion and oxidation resistance at 1500° F. A photomicrograph of a joint after testing in air is shown in Fig. 10.

The 80Ni – 10Cr – 10P alloy was shown to possess fair resistance to attack. An undesirable characteristic of some phosphorus-containing alloys should be mentioned, however. Experiments have indicated that extreme brittleness may be present owing to the formation of complex intermediate phases. This condition is evident in the alloy 88Ni – 12P, which is shown in Fig. 11. The propagation of cracking through the brittle Ni_3P phase is further shown in Fig. 12, a photomicrograph of the alloy at higher magnification.

No precious-metal alloys were tested in sodium, since earlier research in the field indicated that a definite imcompatibility existed at these elevated

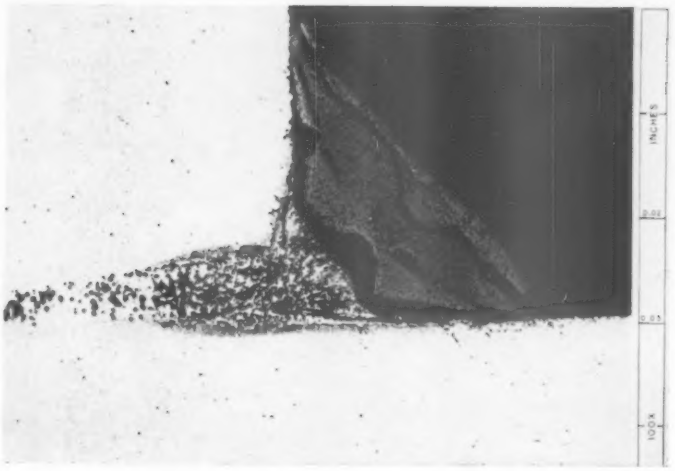

Fig. 14 Photomicrograph of a T-joint brazed with 60Mn – 40Ni after testing in static air for 500 hr at 1500° F

Note the poor oxidation resistance of alloy. X 100. (Reduced by one-third upon reproduction.)

temperatures. An example of typical attack on these alloys is shown in Fig. 13 a photomicrograph of a T-joint brazed with 60Pd – 37Ni – 3Si and tested for 100 hr in sodium at 1500° F.

Although most alloys tested exhibited a high degree of oxidation resistance, a few, such as the 60Mn – 40Ni alloy, were severely attacked. An Inconel joint brazed with this alloy and oxidized for 500 hr at 1500° F is shown in Fig. 14.

Conclusions

As a result of this investigation the following conclusions are justified:

1. Many of the brazing alloys which were investigated possessed excellent resistance to sodium corrosion and oxidation. Alloy systems of the Ni-Si-B, Ni-Cr-Si-B and Ni-Cr-Si types were found to be compatible in both media. Precious-metal alloys were, in general, severely attacked by sodium, as were many of the silicon-free, chromium-free, phosphorus-bearing alloys. Alloys containing manganese, tin or copper exhibited poor resistance to oxidation at 1500° F. In most cases, oxidation was more pronounced at 1700° F.

2. In evaluating the corrosion and oxidation resistance of a brazing alloy, emphasis should be placed on the seesaw and cyclic results, since these tests more nearly simulate the expected operating conditions than do the static tests. It must be remembered, however, that before a brazing alloy is selected for a given type of service, it should be tested further under those conditions which would actually be encountered.

Acknowledgment

The authors wish to express their appreciation to personnel of the Welding and Brazing Group and the General Corrosion Group of the Metallurgy Division for their assistance in the preparation and testing of specimens. Appreciation is also expressed to members of the Metallography Section of the Metallurgy Division for their extensive contribution in the preparation of samples and photomicrographs. In addition, the authors wish to thank the Wall Colmonoy Corp. for supplying a number of brazed specimens for test purposes.

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(Continued on page 234-s)

NOTCH-TOUGHNESS CHARACTERISTICS OF SUBMERGED-ARC WELD DEPOSITS

Investigation shows that the notch-toughness characteristics of submerged-arc weld deposits used for a given steel can vary widely, but are reproducible for a given procedure and weld-deposit composition

BY I. L. STERN, N. A. KAHN AND H. NAGLER

Introduction

In considering the notch-toughness properties of submerged-arc weld deposits, it is desirable to review briefly some of the concepts of notch toughness, notch sensitivity and the phenomenon of transition of ferrous metals from ductile to brittle behavior.

The stimulus for these studies had been the sudden failure of several merchant ships under seemingly normal loading conditions. In each case the ship's structure failed in a brittle manner and the fracture had progressed across many plates; some ships had actually split in half.

Conventional mechanical tests indicated that the tensile strength and ductility of the steel involved in the failure were in conformity with the requirements of the original purchase and design specifications. A study of the failures[1] and a search for measures designed to prevent future failures initiated a series of research programs out of which the current concept of the nature of brittle fractures in structural steel was evolved.

Brittle behavior is generally associated with sudden failure, extremely rapid propagation of fracture and a fracture which shows little or no plastic deformation, whose surface is bright and crystalline in appearance. This type of fracture has been designated as a brittle or cleavage fracture.

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Part of the data reported herein have been presented in a thesis submitted in partial fulfillment of the requirements for the degree of Master of Metallurgical Engineering at the Polytechnic Institute of Brooklyn.

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The opinions expressed herein are those of the authors and do not necessarily represent the opinions of the Navy Department.

Paper presented at 1956 AWS National Fall Meeting, Cleveland, Ohio, Oct. 8–12.

Fig. 1 Typical fractures—Navy Tear Test

In contrast, ductile behavior is associated with a gradual separation, a comparatively slow rate of propagation of fracture and finally a fracture which exhibits appreciable plastic deformation and whose surface is dull and fibrous in appearance. This type of fracture has been designated a ductile or shear fracture.

In some instances, the mode of fracture may change from shear to cleavage as the fracture progresses. These fractures are referred to as "mixed." Typical examples of ductile, mixed and brittle fractures are shown in Fig. 1.

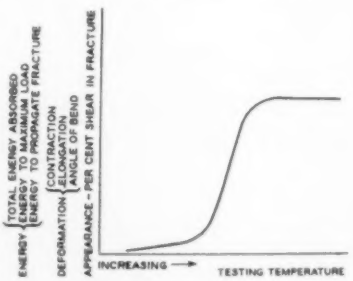

ENERGY (TOTAL ENERGY ABSORBED, MAX. LOAD, ENERGY TO PROPAGATE FRACTURE)
DEFORMATION (CONTRACTION, ELONGATION, ANGLE OF BEND)
APPEARANCE – PER CENT SHEAR IN FRACTURE
INCREASING
TESTING TEMPERATURE

Fig. 2 Schematic illustration of transition temperature range

For a given steel, the type of fracture may change from ductile to brittle behavior by (1) increase in the rate of application of load,[2] (2) introduction of multidirectional stresses or points of restraint or stress concentration (such as notches, cracks or sharp corners),[3–6] (3) lowering of the temperature at which the stress is applied.

Figure 2[7] illustrates in a schematic manner the transition from ductile to brittle behavior as affected by change in temperature of test. The criterion for the test may be (*a*) a change in energy absorption and (*b*) a change in deformation or change in the fracture appearance.

Figure 3[7] shows the effect of notch severity on the transition characteristics of a steel. It may be noted that increased notched severity raised the transition temperature.

Numerous test procedures and specimen designs have been used to reflect the change in behavior during fracture. In the case of some test procedures and specimen designs, the transition is abrupt and a slight change in temperature results in a very marked change in the mode of fracture; in these cases, the temperature at which this transition occurs is logically referred to as the "transition temperature." The change is more gradual with other specimens,

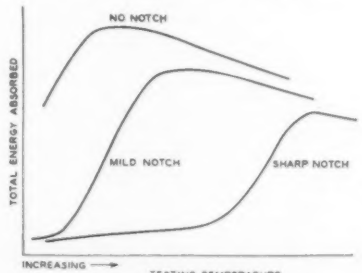


Fig. 3 Effects of notch severity on the transition temperature

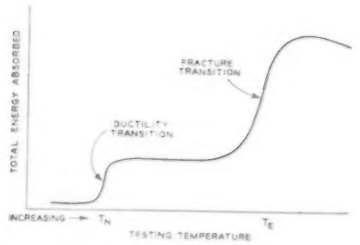


Fig. 4 Ductility and fracture transitions (after Vanderbeck and Gensamer[6])

and arbitrary levels of the criteria are used to reflect the mode of fracture.

In general, notched rather than unnotched specimens are favored for these studies for the following reasons:

(*a*) The tendency toward brittle fracture increases with increased notch severity. The mere introduction of a notch raises transition temperatures so that they occur at test temperatures easier to attain.

(*b*) Service failures of the type previously described usually originated in a notch, or another form of stress-raiser.

The term "notch sensitivity" is being used in relation to these phenomena. Because of the numerous specimen designs and testing procedures which are in use, the term "notch sensitivity" is not rigidly defined. In general, notch sensitivity involves two individual parameters, notch ductility and fracture transition. This is schematically shown in Fig. 4.[7] "Ductility transition" refers to the property of a metal to resist the initiation of a crack. In the case of notched-test specimens, it reflects the ductility of the metal in the immediate vicinity of the notch. The ductility transition temperature is usually established at an arbitrary low level of energy absorption during the formation of a crack. The smaller, more sharply notched specimens, of which the Charpy-vee notch is an example, are in this category.

"Fracture transition" refers to the property of a metal to resist the propagation of a crack after its formation. The property reflects the amount of energy required for the propagation of a crack or fracture. The temperature at which the fracture tends to change from a brittle (cleavage) to a ductile (shear) type has been designated as the "fracture transition temperature." The Navy tear-test method, as well as other large-scale tests reflect this property.[8, 9]

From a consideration of the above, it can be seen that an increase in "notch sensitivity" implies an "increase in transition temperature" or "increase in tendency toward brittle fracture."

A study of the notch sensitivity of a weld assembly necessarily involves a consideration of the prime plate, the heat-affected zones and weld deposit proper.

Numerous studies of the notch sensitivity properties of rolled plate have been and are currently being conducted. Some of the factors which have been shown to affect notch toughness are:[5–19]

(*a*) Composition.
(*b*) Deoxidation practice.
(*c*) Grain size.
(*d*) Finishing temperatures.
(*e*) Plate thickness.
(*f*) Heat treatments.
(*g*) Fatigue.

Many of the factors noted above are interdependent and can vary in effect with other known factors which may be present, as well as many factors which are still unknown.

In the case of a welded assembly, additional factors are introduced by the variables inherent in the welding procedure.[17] These make study of the weld and heat-affected zone even more complex than that of the base metal proper.

Because of the extensive application of welding most modern fabrications represent continuous structures. Since the continuity of an area represents the maximum length that a fracture can propagate, the importance of a complete understanding of the notch-sensitivity properties of welded assemblies as well as that of the prime plate itself can be readily appreciated.

The possibility that a weld metal which tends to have poor notch-toughness characteristics may be a contributory factor in a major failure is fairly obvious. However, the possibility also exists that the use of weld metal of proper notch-toughness characteristics might serve as crack arresters and arrest the propagation of a major failure.

The submerged-arc welding process is frequently used for long continuous welds in assemblies. Therefore, the development of information relative to

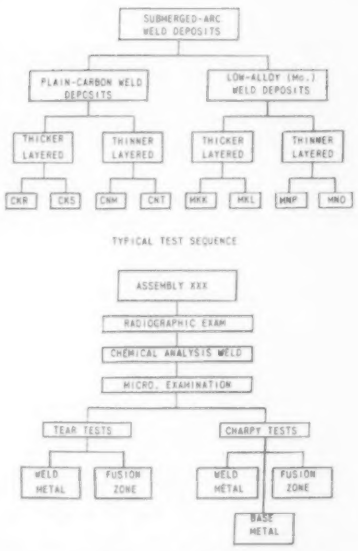
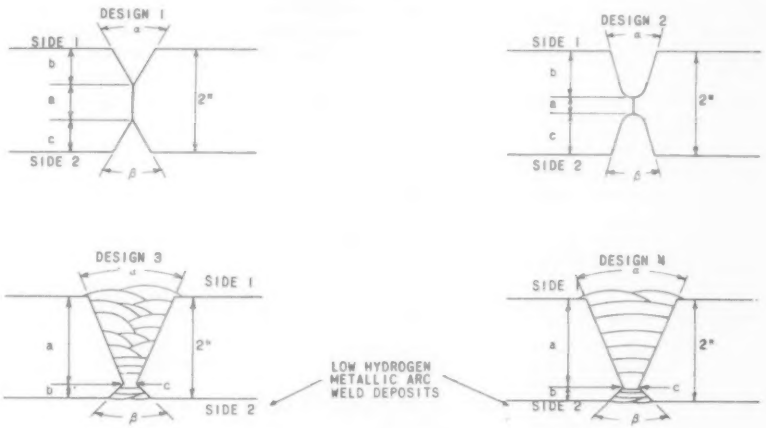


Fig. 5 Experimental design—Series 1 weld deposits and typical test sequence

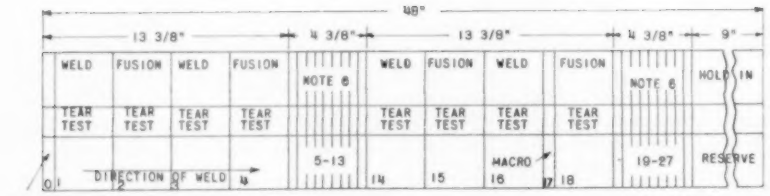


DETAILS OF PROCEDURE

ASSEMBLY	DESIGN	α°	β°	a°	b°	c°	NO LAYERS* SIDE 1	NO LAYERS* SIDE 2	FILLER WIRE	FLUX	PROCESS	COMPOSITION WELD DEPOSIT (%) C.	Mn.	Mo.
CKR	1	50	60	1/2	3/4	3/4	1	1	A	B	X	0.16	1.35	0.00
CKS	1	50	60	1/2	3/4	3/4	1	1	A	B	X	0.16	1.34	0.00
MKK	1	60	60	3/8	13/16	13/16	2	2	C	D	Y	0.14	1.07	0.46
MKL	1	60	60	1/4	7/8	7/8	3	3	C	D	Y	0.13	1.13	0.53
CNT	2	30	30	3/16	1 1/16	3/4	6	5	A	B	X	0.11	1.34	0.00
CNM	3	45	90	1 3/4	1/4	3/16	AS SHOWN		A	B	X	0.10	1.55	0.00
MNP	4	45	90	1 5/8	3/8	1/8	AS SHOWN		C	D	Y	0.11	1.55	0.62
MNO	4	45	90	1 5/8	3/8	1/8	AS SHOWN		C	E	Y	0.06	1.14	0.59

* FULL WEAVE

Fig. 6 Details of joint design and details of procedure



NOTE:
1. 1/8" saw-cut allowance between specimens.
2. Charpy specimens 7, 9, 11, 13, 19, 21, 23 and 25 were notched through the center of the weld.
3. Charpy specimens 8, 8, 10, 12, 20, 22, 24 and 26 were notched longitudinally through the plane where a line through half the thickness of the specimen intersected the edge of the weld.
4. Details of the test specimens are shown in Figure 5.
5. Base-metal Charpy specimens were machined from specimens 13, 19 and 21.
6. Eight Charpy specimens and one macrospecimen were obtained from this section.

Fig. 7 Location of test specimens

the transition properties of these deposits is particularly desirable. A search of the literature reveals that most investigators have been concerned primarily with the metallic-arc welding process, and information relative to the notch-toughness properties of submerged-arc weld deposits, is comparatively sparse[20–26] and a comprehensive evaluation of the range of properties which could be introduced by the usual variations in materials and procedures in submerged-arc welding is practically nonexistent.

A study of the notch-toughness properties of submerged-arc weld deposits presents many facets for investigation. It has been noted that studies on comparatively homogeneous rolled plate manufactured under controlled conditions indicate that many factors are involved in determining the notch-toughness properties of a steel. The effects of these factors are interrelated and their effects can be modified by each other. In addition, all the factors involved are not known. Submerged-arc weld deposits represent an unhomogeneous structure, formed under more variable conditions. Furthermore, the weld can be made with a multitude of different operating conditions.

A broad survey of the properties of all types of submerged-arc weld deposits is obviously beyond the scope of any single investigation. Therefore, the investigation was confined to a determination of the notch-toughness characteristics of several typical weld deposits representative of current commercial practice. Since it was realized that variations in procedure may have a marked effect on the properties, the effects of some typical variations in production techniques were also studied. In view of the close structural relationship of the heat-affected zone of the base metal to the weld proper, an evaluation of the notch-toughness properties of these areas was also attempted.

Metallic-arc welds are frequently considered as equivalents of submerged-arc welds, or are used in conjunction with submerged-arc weld deposits, either as composite welds or for sections of an assembly which cannot be positioned. Therefore, an effort was made to compare the notch-toughness properties of welds deposited by both processes.

Procedure

The tear test as developed by Kahn and Imbembo[3] and the Charpy vee-notch tests were selected for this program, after due consideration of the various test methods.

In the tear-test method, the test specimen of Fig. 8 is loaded with a cross-head

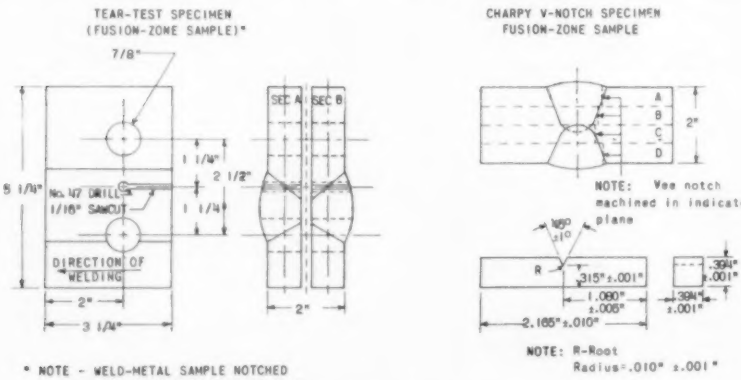


Fig. 8 Procedure for machining tear test and Charpy specimens

speed of 0.05 ipm. The test criteria are energy to propagate fracture and type of fracture as denoted by its appearance (shear or cleavage). This test, which employs a comparatively slow rate of loading, serves to indicate the fracture transition temperature, i.e., the ability of a material to resist propagation rather than initiation of a crack.

The tear test appeared particularly useful for this application for the following reasons:

1. Specimens used reflect the composite properties of an appreciable thickness of weld deposit. This is particularly important in the case of submerged-arc weld deposits because of the nonhomogeneity of the structure. In those tests which employ comparatively small sizes of specimens, results obtained only reflect the properties at the specific level of thickness from which the specimen is selected, consequently requiring a large number of samples and tests for the evaluation of a joint of appreciable thickness.

2. In the tear test, change from a brittle to a ductile failure occurs over a comparatively small temperature range. Therefore, tests at a given temperature within the ductile or brittle range would tend to show consistent results.

3. Test specimens can be prepared with comparatively little cost. In addition, interpretation can be made by visual examination of the resultant fracture.

Charpy-vee notch tests represent a faster rate of loading and more acute notch. The values obtained in this test reflect a combination of the factors involved in cracking, energy required for formation of a crack (ductility transition) and energy absorbed during its propagation (fracture transition). Numerous comparative transition data have been accumulated with this standard. In addition, an empirical relationship has been shown between the 15 ft-lb Charpy-vee transition temperature and brittle fractures of welded ships.

To accomplish the outlined objectives the following groups of assemblies were investigated:

(*a*) Series 1. Eight submerged-arc weld assemblies in 2-in. thick HTS* plate were fabricated in accordance with the experimental design of Fig. 5. For comparative purposes a ninth assembly fabricated with Type 7016 low-hydrogen electrodes was also investigated. These assemblies were obtained from various shipyards and were considered representative of current techniques.

(*b*) Series 2 consisted of 10 submerged-arc weld assemblies in 2-in. thick Navy Grade HTS plate.* For

* Nominal analysis (% maximum unless otherwise specified) C 0.18, Mn 1.30, P 0.04, S 0.05, Si. 0.15–0.35, Ni 0.25, Cr 0.15, Mo 0.06, Cu 0.35, Ti 0.005 (min), V 0.2 (min).

this series the fabricators were acquainted with the results of tests of the Series 1 assemblies and then requested to submit welds representative of optimum notch-toughness properties.

(*c*) For series 3, assemblies were made in $1^1/_4$ and 2 in. thicknesses of high-tensile steel with various types of metallic-arc welding electrodes (6010, 6011, 6020, 7016 low hydrogen).

In the case of the coded assemblies, the following code identification system has been used:

1st letter: "C" for carbon steel deposit, "M" for deposit containing over 0.30% molybdenum.
2nd letter: "K" for relatively thick layers, "N" for relatively thin layers.
Last letter: code identification of assembly.

In the case of the metallic-arc weld deposits, the numbers indicate the electrode type and the letter indicates the Code letter of the assembly.

Figure 5 indicates the experimental design and test sequence used for the Series 1 submerged-arc welded assemblies. Carbon and low-alloy (molybdenum) steel weld deposits of thick and thin layers were investigated. As indicated therein, the following tests were conducted on each assembly:

(*a*) Radiographic examination.
(*b*) Chemical analysis of weld deposit.
(*c*) Macroexamination.
(*d*) Navy tear tests:
  (1) Weld metal.
  (2) Fusion zone.
  (3) Base metal.
(*e*) Charpy vee-notch tests:
  (1) Weld metal.
  (2) Fusion zone.
  (3) Base metal.

Details of joint designs, welding procedures, weld deposit compositions and machining details of test specimens are shown in Figs. 6, 7 and 8.

Tests of the series 2 and 3 assemblies were similar except that fusion-zone and base-metal tear tests and all Charpy tests were omitted.

Results

Results of tests of the Series 1 assemblies are shown in Figs. 9 to 15 and Table 1.

Results of the Series 2 assemblies are shown in Table 2.

Results of tests of the supplementary metallic-arc welded assemblies are shown in Table 3.

A comparison of all tear-test results obtained is shown in Fig. 17.

Figures 9 and 10 indicate the effects of variation in pass sequence on the tear-test transition characteristics of submerged-arc weld deposits. Referring to Fig. 9, assemblies CNM and CNT which represent carbon-steel welds of many passes and relatively thin layers, exhibit somewhat lower transition temperatures than the corresponding welds of few, heavy passes (assemblies CKR and CKS).

In Fig. 10, it is shown that for the low-alloy (Mo) weld deposits the reverse is true, and the weld deposits of fewer and thicker passes (MKK and MKL) exhibit appreciably lower transition temperatures than those consisting of many thin passes (assemblies MNO and MNP).

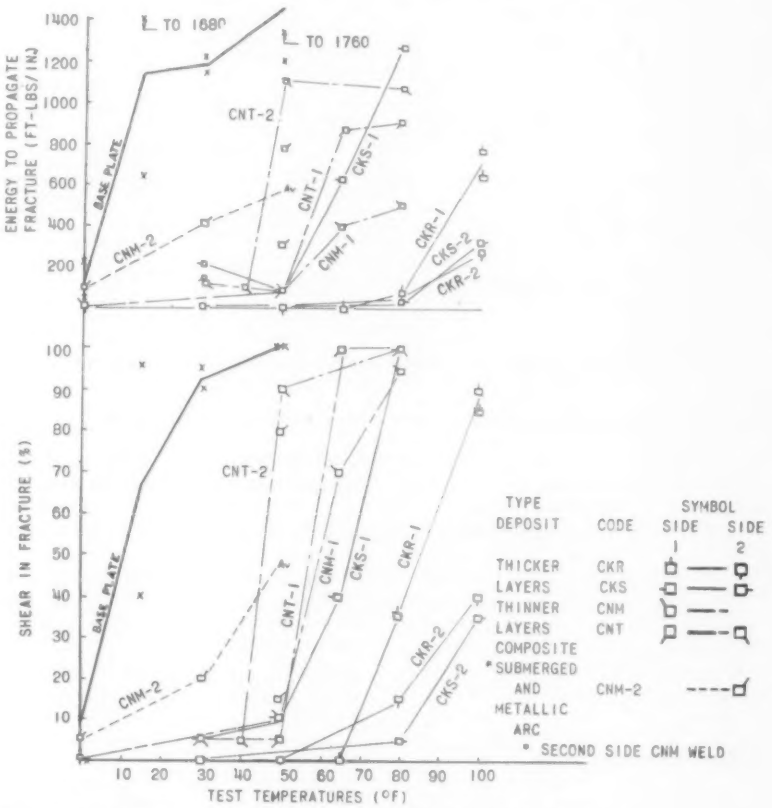


Fig. 9 Results of tear tests (carbon-steel weld deposits)—Series 1

Table 1—Comparative Tear Test and Charpy Results—Series 1

			Charpy vee-notch value at 0° F			*Tear-test transition temperature range**		
Weld deposit	*Layer sequence*	*Assembly*	*Weld*	*Fusion zone*	*Base metal*	*Side*	*Weld*	*Fusion zone*
Carbon steel weld deposit	Thick	CKR	21.3	47.2	68.1	1	80–100	30–100
						2	>100	50–80
		CKS	20.3	41.4	68.1	1	50–80	30
						2	>100	—
	Thin	CNM	33.1†	39.8†	68.1	1	50–80	30–50
						2‡	>50	30–50
		CNT	27.2	38.1	68.1	1	50–65	30–50
						2	40–50	15–30
Low Alloy (molybdenum) steel weld deposit	Thick	MKK	36.8	44.8	33.0	1	0–15	−20–0
						2	15–30	0–30
		MKL	28.5	37.0	33.0	1	15–50	−40 to −20
						2	0–15	0–30
	Thin	MNO	13.5†	19.2†	21.7	1	>100	30–100
						2‡	50–65	0–30
		MNP	18.9†	24.5†	21.7	1	80–100	50–100
						2‡	65–80	50–80

* Range over which major change from cleavage (brittle) to shear (ductile) type fracture occurred.
† Submerged-arc weld levels only.
‡ Composite submerged-arc, low hydrogen weld deposit.

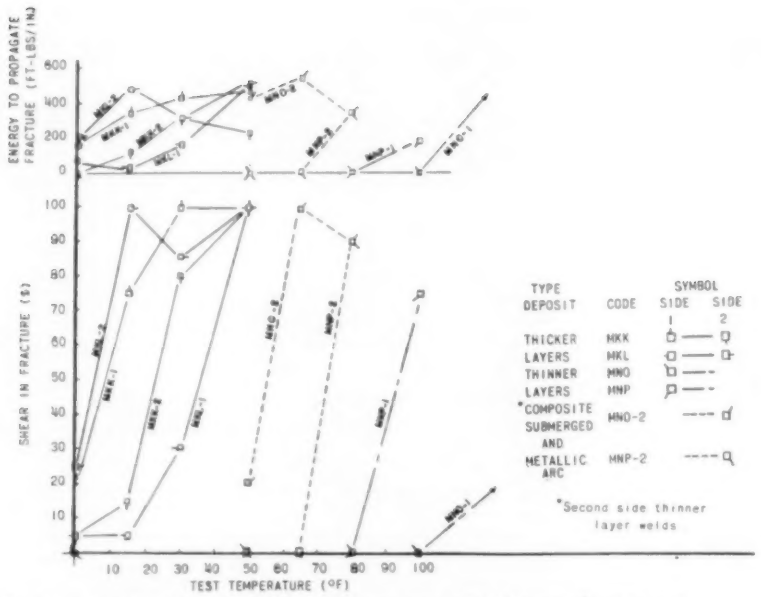


Fig. 10 Results of tear tests (molybdenum-steel weld deposits)—Series 1

Both Figs. 9 and 10 indicate that the thickness half containing the composite metallic, submerged-arc deposit exhibited a lower transition temperature than the thickness half which contained all submerged-arc weld. However, these results are applicable only to the particular assemblies involved, wherein the submerged-arc weld deposits exhibited comparatively high transition temperatures. It is probable that if a submerged-arc weld deposit of appreciably lower transition temperature were involved, the composite welds might exhibit higher rather than lower transition temperatures.

Summaries of Charpy results are shown in Figs. 11 and 12. In the case of assemblies CNM, MNP and MNO, the values from the lowest level ("D") specimens which contained composite submerged-arc, metallic-arc weld deposits or all metallic-arc weld deposits were not included in the average values shown. A study of the data shows that the various relationships indicated by the tear test are also indicated by the Charpy tests.

Figure 13 indicates the correlation in notch toughness properties of the weld deposits which was found between the results of Charpy and tear tests. In this comparison, the temperature corresponding to 50% shear in the tear test is plotted against the 20 ft-lb Charpy level. The values farthest to the left and lowest represent the most desirable Charpy and tear test characteristics, respectively. It is evident that deposits which tended to give the least desirable Charpy results also tended to give the poorest results in tear tests, and those exhibiting the best Charpy characteristics tended to give the more desirable tear test results. The tear-test and Charpy results are not always related inasmuch as the former only indicates fracture transition whereas the latter also reflects ductility transition; however, Fig. 13 indicates that both were affected similarly.

Figures 14 and 15 indicate comparative data for the low-hydrogen weld assembly. The values obtained are representative of a notch toughness characteristic intermediate between the best and poorest of the submerged-arc welds.

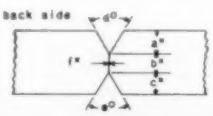
Fusion Zone Properties

The determination of the notch-

Table 2—Supplementary Submerged-Arc Weld Deposits—Series 2

PROCEDURE TYPE DEPOSIT	LAYER THICKNESS	FILLER CODE	ROD	FLUX	JOINT DESIGN**** a°	b°	c°	d°	e°	f°	PASS SEQUENCE 1st SIDE NO. LAYERS	1st SIDE NO. PASSES	2nd SIDE NO. LAYERS	2nd SIDE NO. PASSES	COMP. DEPOSIT % C.	Mn.	Mo.	TEAR-TEST TRANSITION RANGE - WELD DEPOSIT SIDE 1	SIDE 2	PROCESS
		H	F	G	7/8	1/4	7/8	60	60	0	3	3	3	3	0.08	1.23	0.25	>80	15-65	X
	Thick Layers	I	H	I	7/8	1/4	7/8	60	60	0	3	3	3	3	0.07	0.96	0.01	30-70	0-30	X
Plain Carbon Steel		F	H**	D	1	3/8	5/8	60	90	1/16	3	3	2	2	0.09	1.15	0.00	60-70	80-90	Y**
		B	J	I	1 9/16	1/8	5/16	45	30	1/8	9	16	***	***	0.12	1.17	0.02	50-70	10-15	X
	Thin Layers	C	A	K	1 9/16	1/8	5/16	45	60	1/8	9	15	***	***	0.08	1.08	0.00	50-85	65-80	X
		D	H	I	1 9/16	1/8	5/16	45	60	1/8	9	17	***	***	0.10	0.92	0.01	0-30	20-30	X
		G	H	D	1 1/2	1/8	3/8	10	90	1/8	6	12	2	2	0.00	0.97	0.00	50-70	Over 30	Y
		U	H	D	1 5/8	0	3/8	45	90	1/8	7	9	4	5	0.08	1.27	0.00	40-70	40-70	Y
Low-alloy >0.30 Molybdenum	Thick Layers	E	C**	L	1	3/8	5/8	60	90	1/16	3	3	2	2	0.10	0.81	0.33	60->80	15-30	Y**
	Thin Layers	V	C	D	1 5/8	0	3/8	45	90	1/8	7	12	4	8	0.08	1.25	0.49	80->100	20-30*	Y

*- Composite submerged and metallic-arc deposit
**- Twin-arc procedure
***- Flux backing submerged arc sealing bead from back side
****- All joints double-vee except assembly "G" for which the first side is a "U"



toughness properties of the bond zone of the Series 1 welds represented a more complex problem than that of the weld metal. Transitions in structure and even composition vary abruptly in this zone. A consideration of the joint designs involved as well as the contour of the resulting weld will indicate the varied possibilities for location of a notch in this zone. The particular "fusion zone" specimens selected for both Charpy and tear tests are shown in Fig. 8. These were considered to be the most representative specimens which could yield information relative to this zone and yet be commensurate with the scope of the investigation.

A consideration of the fusion zone will indicate that the following variables complicate the interpretation of test results:

(*a*) The variable transition properties of the base metal and weld deposit.

(*b*) The differences in amounts and areas of base plate, fusion zone and weld deposit included in the various specimens.

(*c*) The varying geometric relationships between base metal, fusion zone and weld deposit encountered as a result of the inherent differences in contour of the welds and joint designs utilized. The role of these relationships could not be estimated readily.

In view of the above, it was believed that any conclusions as to relationships between the fusion zone results of different assemblies could be misleading and invalid and would be more dependent on the foregoing factors than on the properties of the heat-affected area of base metal. Consequently, these relationships have not been included in this report. However, Table 1 summarizes the general relationships found between fusion zone, weld metal and base metal. As indicated therein, the tear tests and Charpy tests indicated that, for the particular specimens involved, the fusion-zone specimens consistently exhibited superior notch-toughness characteristics and lower transition temperatures than the corresponding weld-metal specimens. In addition, it was observed that the fractures of the fusion-zone specimens did not usually progress directly along the bond. A typical fracture is shown in Fig. 16. A consideration of these two factors will indicate that, for this particular investigation, the fusion-zone specimens were decidedly less notch-sensitive than those representative of the weld metal.

It should be noted that the fusion-zone specimens employed for the investigation included appreciable areas of base plate and weld deposit in the notch and resultant fracture. It is realized that the results obtained may not be truly representative of the refined metal of the bond proper. How-

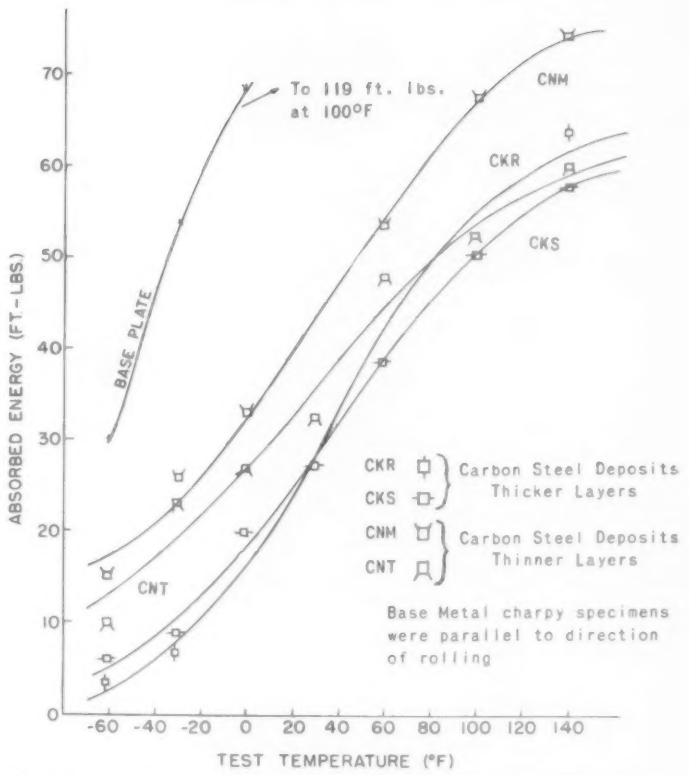


Fig. 11 Results of Charpy vee-notch tests (carbon-steel weld deposits)—Series 1

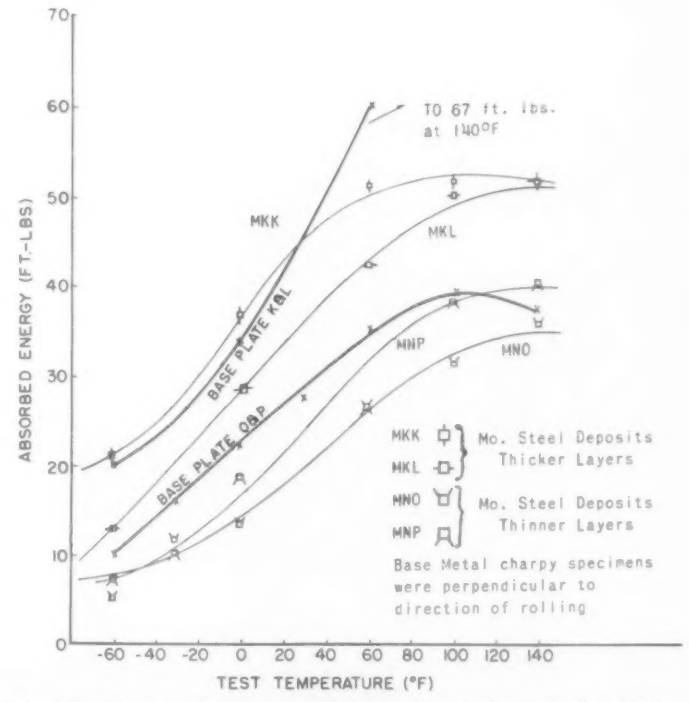


Fig. 12 Results of Charpy vee-notch tests (molybdenum-steel weld deposits)—Series 1

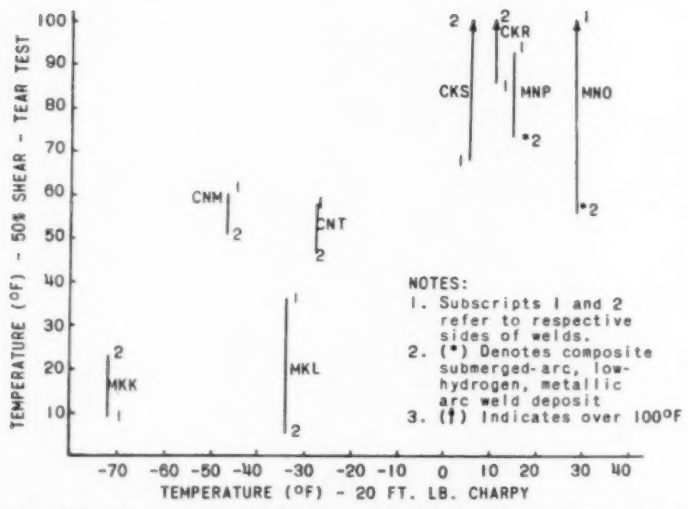


Fig. 13 Comparison of Charpy vee-notch and tear test results—Series 1

ever, a determination of the properties of this zone was considered beyond the scope of this investigation.

Supplementary Submerged- and Metallic-Arc Welds

As indicated in Table 2, results of the Series 2 supplemental submerged-arc welded assemblies, which were submitted as being representative of welds of desirable notch-toughness properties, indicate that current commercial materials and procedures yield welds of varying notch-toughness properties. In a few cases, sections of these weld deposits exhibit tear-test properties which are inferior to those of metallic-arc welds.

As indicated in Table 3, results of tests of the supplementary metallic-arc weld deposits indicate that the tear-test transition range of these deposits is intermediate between the lowest and highest transition temperatures measured for the submerged-arc weld deposits. It is evident, therefore, that some of the submerged-arc welding procedures in common commercial use yield weld deposits with notch-toughness properties which are inferior to those actually obtained in metallic-arc welding. It should be noted that the metallic arc specimens were $1^1/_4$ in. thick and the submerged arc $^7/_8$ in.; the heavier thickness of the former tended to yield slightly higher transition temperatures (approximately 10° F higher).

Summary

Figure 17, which summarizes the results of all tear tests, indicates the various tear test relationships noted in the preceding paragraphs.

Figure 17 illustrates the general notch-toughness relationships between the welds and the base metal. As indicated therein, both the submerged- and metallic-arc processes tend to produce welds which exhibit transition temperature ranges appreciably above the base metal level. However, as indicated therein, it is possible to obtain submerged-arc welds comparable in transition properties to those of high-tensile steel base metal. Many of the procedures produced welds exhibiting transition temperatures below 70° F which approximates the level of medium steel plate.

The results of this investigation have indicated the following in respect to the transition temperatures and notch-toughness properties of submerged-arc weld deposits representative of current commercial practice:

(*a*) The properties vary widely between the various weld deposits investigated.

(*b*) The weld metal composition can have a marked effect on the transition properties.

(*c*) The transition temperature of a weld deposit of a given composition can vary widely according to the procedure used in its deposition.

(*d*) No general rule can be made relative to the relationships between weld-layer thicknesses and transition properties. It has been shown that the transition temperature can be either markedly increased or decreased by a modification of pass sequence and thickness, the direction appearing to be dependent upon the particular composition of weld deposit.

(*e*) In many cases, procedures for submerged-arc welding specify that layer thicknesses shall not exceed $^3/_8$ in. In view of the conclusions above, it appears that for some deposits, this procedure will produce welds of the poorest notch-toughness characteristics.

A comparison between the notch-toughness properties of submerged-arc weld deposits and metallic-arc weld deposits commonly used in the welding of high-tensile steel plate indicated that some submerged-arc welds are markedly superior and others markedly inferior to those obtained with the metallic-arc process.

While most submerged-arc welds exhibited tear-test properties inferior to the 20° F transition temperature level (ductile at 30° F) established for the base metal, several procedures produced welds exhibiting transition temperatures of 20° F or below.

For the particular direction of loading and weld deposits investigated, the weld proper had transition characteristics which were inferior to the fusion zone and base metal.

Transition properties of weld deposits appear reproducible for any given procedure.

The foregoing results have indicated that the notch-toughness characteristics of submerged-arc weld deposits are subject to wide variations which are, for the present, unpredictable. However, transition properties of weld deposits appear reproducible for any given procedure. A determination of the role of

Table 3—Metallic-Arc Weld Deposits Series 3

Electrode type and code	*Plate thickness, in.*	*Pass sequence** 1st side *No. layers*	*No. passes*	2nd side *No. layers*	*No. passes*	*Tear-test transition range, weld deposit*
7016N	2	8	22	8	21	50–80* 80–100†
7016W	2	8‡	17	8*	17	60–70† 40–60*
7016A	$1^1/_4$	6‡	10	6*	10	60–90
6011X	$1^1/_4$	5‡	7	5*	7	50–80
6020-Y	$1^1/_4$	5‡	7	5*	7	40–60
6010-Z	$1^1/_4$	6‡	9	6*	10	40–60

‡ First three layers each side, full width weave. All joints—double vee, 60 deg included angle.

* One side welded flat.

† One side welded overhead.

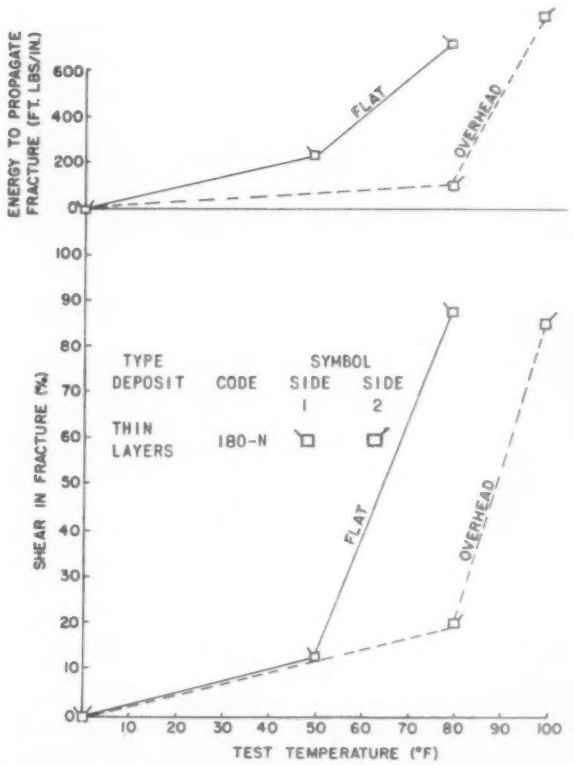


Fig. 14 Results of tear test—carbon steel weld deposits—low-hydrogen, metal-arc weld deposits—Series 1

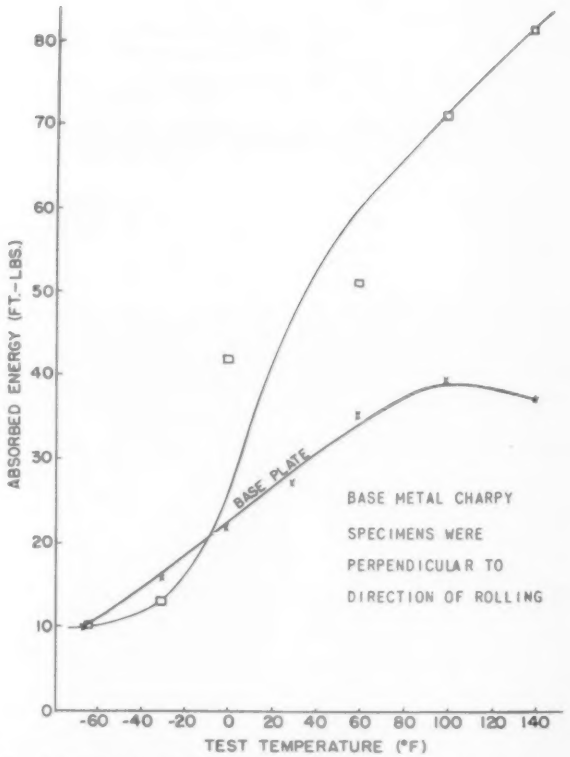

ABSORBED ENERGY (FT.-LBS.)
TEST TEMPERATURE (°F)
BASE PLATE
BASE METAL CHARPY SPECIMENS WERE PERPENDICULAR TO DIRECTION OF ROLLING

Fig. 15 Results of Charpy vee-notch tests—low-hydrogen, metal-arc weld deposits—Series 1

the various factors which influence the transition characteristics of weld deposits would be even more complicated than that of the analogous study of rolled plate because of the less uniform compositions involved as well as the additional variations introduced by the welding procedure. In view of the results obtained, it is believed that the development of more information relative to the specific factors which influence weld metal transition would be desirable.

Significance

In view of the broad range of transition properties which can be introduced in a submerged-arc weld deposit by comparatively small variations in procedure, it is believed that these properties should be considered in each qualification procedure for structural applications where desirable notch-toughness properties of the weld deposit are required. This appears particularly important since it has been shown that, in some cases, the resultant submerged-arc weld deposit can have notch-toughness properties which are markedly inferior to metallic-arc weld deposits as well as to the base metal proper.

Sufficient information is not presently available to relate results between various procedures and weld-metal compositions. Consequently, it appears that in those cases where notch sensitivity is an important consideration, qualification of a particular submerged-arc weld deposit should be limited to the particular procedures and heat treatments used in the fabrication of the assembly subjected to notch-toughness tests. The evaluation of the suitability of an assembly in respect to notch toughness, would not necessarily require the determination of the exact transition temperature. Determination of the occurrence of a ductile type fracture at a specific temperature in one or more of the conventional tests for transition properties should prove sufficiently selective for qualification purposes.

In the case of submerged-arc welds in high-tensile steel, a suggested procedure is to require tear tests to be conducted through three locations in an assembly. Ductile fractures of specimens up to 1 in. thick should be required at test temperatures of either 60 or 30° F. The former temperature represents the equivalent of a metallic-arc weld deposit; the latter the level established for normalized high-tensile steel base plate.

This investigation has been concerned with the longitudinal notch-toughness properties of weld deposits. No attempt has been made to assess transverse notch-toughness properties which indicate the potential applicability of weld deposits as crack arresters. The complex base metal, fusion zone and weld deposit interactions which would be involved in these studies were considered well beyond the scope of this investigation. However, a study of this aspect should provide valuable information relative to the crack arresting potentialities of submerged-arc welds in major structures.

Acknowledgments

The authors wish to express their appreciation to the Wrought Metals Research Section of the Material Laboratory, New York Naval Shipyard, for their assistance in obtaining some of the data and to the Bureau of Ships, the Director of the Material Laboratory, New York Naval Shipyard and the Polytechnic Institute of Brooklyn for their permission for publication.

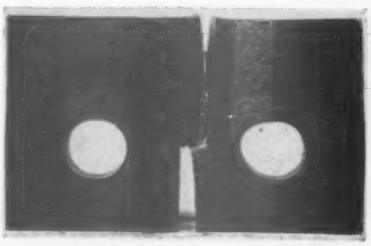


Fig. 16 Typical mode of fracture for tear-test specimens notched in fusion zone

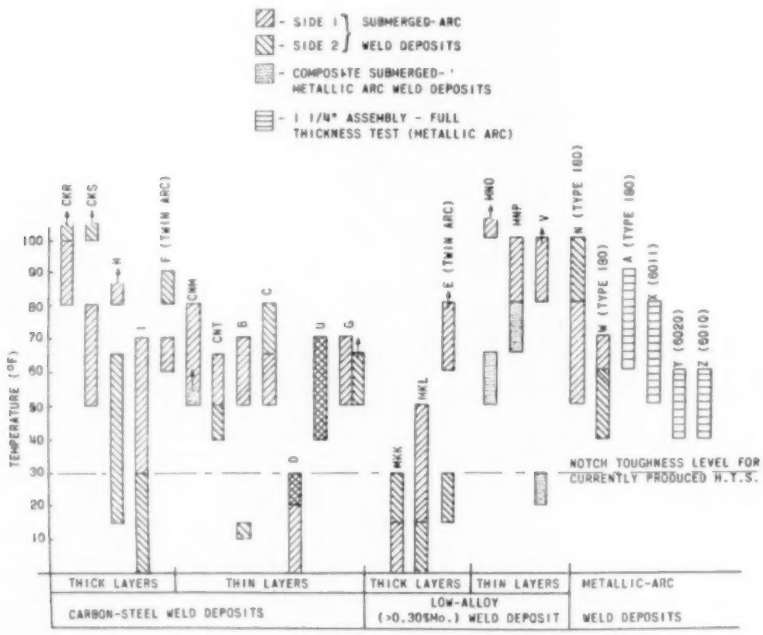


Fig. 17 Tear-test transition ranges

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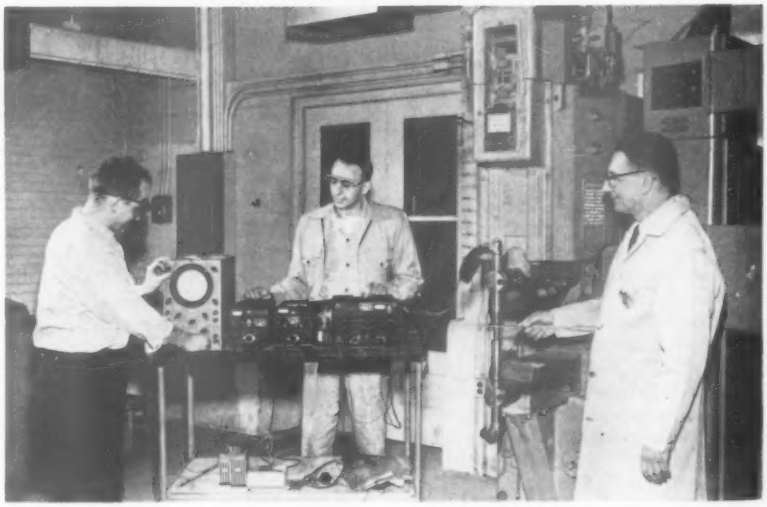
TIP-LIFE STUDIES IN THE SPOT WELDING OF 5052 ALUMINUM ALLOY

Data indicate that 1050 lb tip force and 10-in radius dome electrode produce best tip life when welding 5052 aluminum alloy

BY RICHARD A. DAVIS AND ROBERT C. McMASTER



Equipment used in spot welding investigation at Ohio State University

Introduction

The Welding Practices Subcommittee of the Resistance Welder Manufacturers Association has sponsored a continuing investigation of the spot welding of 5052 aluminum alloy to commercial specifications at The Ohio State University. This research has been devoted to the determination of welding schedules for 5052 aluminum alloy in 0.051- to 0.051 in. sheet thickness combinations and to the determination of tip-life characteristics under commercial welding conditions.*

The purpose of this research was to investigate the spot welding of 5052 —1/4 H alloy to commercial rather than military specifications. Commercial strength specifications were established by the Welding Practices Subcommittee for this study, at 80% of military strength specifications. These requirements fix the lowest allowable *average* shear strength for 0.051-in. sheet at 438 lb per spot and the lowest allowable static shear strength on any specimen as 354 lb. Since numerous welds were sectioned for metallographic examination, nugget diameter was used to predict the shear strength of these welds. On this basis, using 19,000 psi ultimate shear strength,† the lowest allowable *average* nugget diameter was 0.171 in. and the lowest allowable nugget diameter for any specimen was 0.154 in.

In these tip-life studies, "tip life" was defined as the number of welds that could be made prior to the first evidence of alloying of the electrode copper with the aluminum alloy sheet material. The weld checked in Fig. 1 shows the first tip pickup in a typical run.

At the outset of this research an effort was made to establish welding schedules using No. 2 Morse taper, 5/8-in. diam, 4 in. radius, dome-shaped electrodes with tip forces during welding in the range of 400 to 700 lb. These conditions were selected as typical commercial welding conditions. With the lower tip forces, very few welds (6 to 10) could be made before tip pickup occurred. Higher tip forces up to 1500 lb were then investigated.

Test Equipment and Procedure

All welds were prepared on a 150-kva, air-operated press type spot welder. This machine operates from single-phase, 60-cycle, 220-v mains. A single-

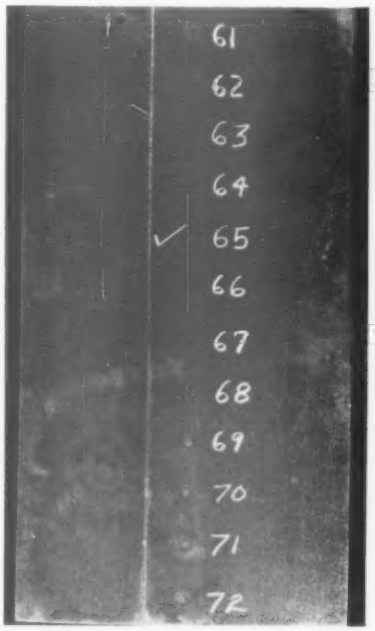


Fig. 1 Typical tip-life test panel; the weld checked (√) is the first indication of tip pickup

Richard A. Davis is student in Welding Engineering, and **Robert C. McMaster** is Professor of Welding Engineering, Engineering Experiment Station, Ohio State University, Columbus, Ohio.

*See Appendix for Description of *Commercial Quality*.

Paper presented at 1957 AWS National Spring Meeting, Philadelphia, Pa., April 8–12.

†Alcoa Structural Handbook.

pressure force cycle was used in all tests.

Welding Electrodes. All welding electrodes used in this research were RWMA Class I electrodes with fluted water cooling channels. Although No. 2 Morse taper $^{5}/_{8}$-in. diam electrodes in standard electrode holders were used primarily in these tests, some tests were made with No. 3 Morse taper, $^{7}/_{8}$-in. diam electrodes in heavy-duty electrode holders for comparison.

Before each tip-life study, several pairs of electrodes were cleaned and radiused to a 4- or 10-in. radius dome as desired. This was accomplished on a lathe by cutting tools designed to form 4- and 10-in. radius domes. Just before welding, dirt and grease were cleaned from the electrodes with acetone.

Welding Schedules. In developing welding schedules, tests were made throughout the range of 6- to 12-cycle weld time. After several trials, 9-cycle current duration was found to be optimum. Sixty-cycle squeeze time was selected to insure a constant force during welding and 60-cycle hold time to insure no change during cooling. With this schedule, welds were made at the average rate of 2.7 sec per weld during tip-life studies.

Weld current magnitudes were selected to produce a $^{3}/_{16}$-in. (0.187-in.) nugget diameter at the faying plane. This value was chosen so as to allow some negative variation in nugget diameter and still be above the minimum requirements.

It was found that the static shear strengths and nugget diameters could be varied measurably by changing the phase-shift heat control dial by only 1% indication. To avoid minor differences in heat settings caused by backlash, the desired percentage heat setting was always approached from one direction (the 100% heat end of the scale).

Measurement of Weld Current. The welding currents flowing in the secondary circuit were determined from primary current measurements and transformer turns ratios. An 800:5 current transformer was placed in the primary power supply lead to the welding transformer. A load resistor was connected across the secondary output terminals of the current transformer and adjusted so that the voltage drop across the resistor produced one unit of pen deflection of the pen recorder for each ampere in the load resistor. Thus, one unit of pen deflection corresponded to 160 rms amperes in the primary circuit. When pen deflection was multiplied by the turns ratio for any particular welding transformer tap setting, an estimate of the secondary welding current was obtained.

Measurement of Electrode Force. Tip forces were measured statically with a mechanical force gage, which was calibrated precisely before tests in a precision gage laboratory. The relationship between the static tip forces so measured and the air pressures indicated in the bellows cushion air pressure gage was established and found to repeat itself consistently. Check tests made with a mechanical force gage indicated that welder tip forces vary ± 25 lb from indicated values under these conditions. A squeeze time of 60 cycles was employed, to allow tip force to reach its final value before welding current was applied.

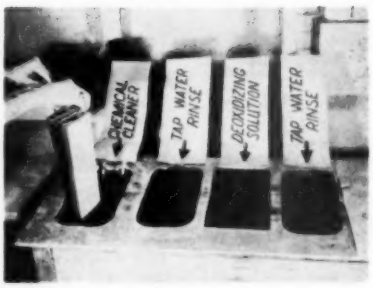


Fig. 2 Small-scale cleaning baths used for cleaning and deoxidizing the aluminum test sheets prior to welding

Preparation of Sheet Materials for Welding. Figure 2 shows the small-scale cleaning baths used for cleaning and deoxidizing the aluminum alloy test sheets prior to welding. The specimens were chemically cleaned to a sheet surface resistance of 8 to 12 microhms by the following procedure:

1. Test sheets were immersed for 5 min in a still solution of degreaser held at 160 to 180 ° F.
2. The test sheets were then rinsed for 5 min in running tap water.
3. Test sheets were then immersed for 4 min (critical) in an etching solution at room temperature.
4. Test sheets were then rinsed for 3 to 5 min in running tap water.
5. Test sheets were then drained until dry by stacking them vertically with spacings, diagonally upon one corner which rested on a cloth that absorbed excess liquid which drained to the bottom. Figure 3 shows the specimens as they are dried.
6. Welds were made within 2 hr after cleaning the test sheets. Frequent surface resistance tests were made with a surface resistance indicator, shown in Fig. 3.

Control of Spot Spacing. All tip-life studies were made with two-layer equal thickness combinations of 0.051-in,. 5052 (52S) aluminum alloy sheets of 12- x 4-in. size. The test panels were overlapped 1 in. Welds were placed 1 in. apart in a single row, with a total of 12 welds per panel. A guide attached to the welder permitted rapid movement of the sheets between successive welds. The first weld in each panel, being an unshunted weld, was excluded from the data herein.

Results of Tests of Tip-Life Studies

Effect on Electrode Characteristics. During preliminary tip-life studies in the higher ranges of force, inconsistencies in tip-life characteristics and short tip lifetimes (6 to 10 welds) were traced to electrode material and shape conditions. Accordingly, changes were made to electrodes with fluted internal water cooling channels and to larger radius domes. The results of these changes were beneficial and improved consistencies were obtained. Investigation of surface finishes varying from a high polish to a rough finish indicated that the best type of finish is a smooth and symmetrical dome, not necessarily highly polished.

In most of the tip-life studies, tip pickup did not occur at the top and bottom electrode at the same time. In some cases, one electrode would last twice as long as the other before pickup occurred. This occurrence was not traced to any property of the electrode or its position (top or bottom electrode holder). The same pair of electrodes in another identical test run could very well reverse the situation. The fact that water flowed through the bottom electrode first seemed to have no favorable influence on the tip life of the bottom electrode.

A check on the amount of water flowing through the electrodes showed that 2 gpm flowed through the holders for $^{5}/_{8}$-in. diam electrodes and $2^{3}/_{4}$ gpm through those for the $^{7}/_{8}$-in. diam electrodes. Cooling-water temperatures during this period of research varied seasonally from 50 to 78° F. During welding, outlet water did not

Fig. 3 Measurement of surface resistance of test specimens; resting on the cloth are specimens being dried

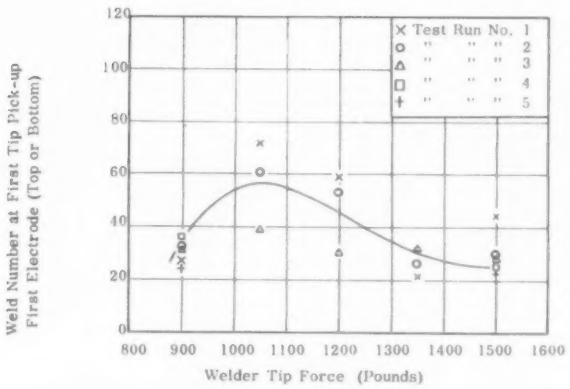


Fig. 4 (*a*) Weld number that the first electrode gave tip pickup in the test run indicated

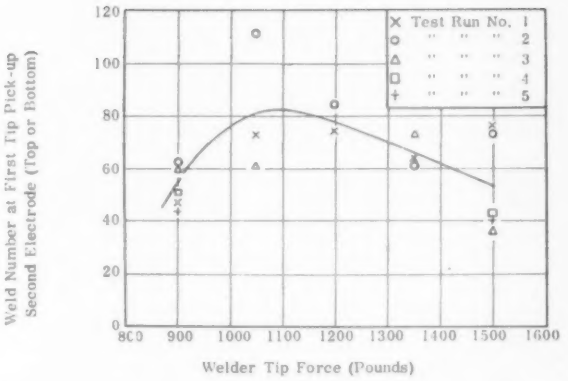


Fig. 4 (*b*) Weld number that the remaining electrode in the same test run gave tip pickup

exceed a 3° F rise over inlet temperature. For optimum performance, the manufacturer of this spot welder recommends water-cooling temperatures under 60° F.

Rockwell "B" hardness tests were performed on electrodes to find if a correlation existed between hardness and tip pickup. Tests on electrodes (1) as received from the factory, (2) after 50 "dud welds" (no current applied) and (3) after lathe machining, gave consistent Rockwell "B" hardness values of 68 ± 2. Electrodes tested after welding had an average hardness of 61R_b within the contact area and 69 R_b elsewhere.

Tip-Life Studies at Various Forces. Tip-life tests were made with 10-in. radius dome, $^5/_8$-in. diam electrodes at tip forces during welding of 900, 1050, 1200, 1350 and 1500 lb, single-pressure force cycle. Prior to each test, welding conditions for the given tip force were established by modifying heat control setting and weld current to obtain welds of identical strengths and nugget diameters, as close as feasible to $^3/_{16}$-in. (0.187-in.) nugget diameter. Sheet surfaces were prepared to 8 to 12 microhm surface resistance. Squeeze time and hold time were both set for 60 cycles. The time per weld, measured by stopwatch on a number of sequential welds, was 2.7 sec per weld, rather consistently, for each panel of 12 successive welds. An average of one weld every 3 sec (or better) was maintained throughout all runs. Welds were made within 2 hr after sheet preparation, for all runs.

Upon completion of welding runs, the sheet surfaces were etched with a dilute water solution of hydrofluoric acid, to reveal areas of tip pickup and alloying with electrode copper. From these test results, an apparent optimum of tip life was obtained with tip force during welding near 1050 lb. These test results are plotted in Fig. 4 (*a*) and (*b*). In any particular test run, tip pickup did not occur in the top and bottom electrode at the same weld number. As a result, tip pickup of the first electrode, in either top or bottom position, is shown in Fig. 4 (*a*) as a function of the welder tip force. Figure 4 (*b*) illustrates the first tip pickup of the remaining electrode.

As can be seen from Fig. 5, the variation in weld current with tip force is as would be expected. As the tip forces are increased, weld-current values for a given nugget diameter increased correspondingly. Prior to starting each tip-life study, the welding current was selected to give the desired nugget diameter.

At least one run, at each force condition, was selected as typical and used for sectioning and metallographic examination, and for static shear tests. In these tests, the first three welds were pulled in static shear, the next three were sectioned for nugget diameter and penetration measurements, and so on, alternately, for each group of three welds, throughout the run. In each case, percent penetration, nugget diameter and shear strength were plotted as a function of weld number. For

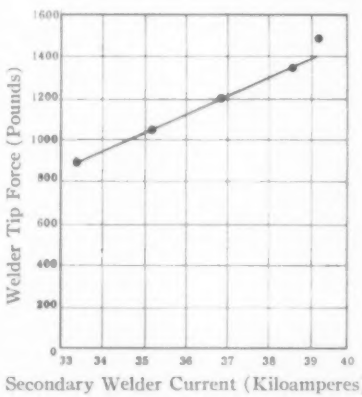


Fig. 5 Secondary welding current as a function of welding tip force for a constant nugget diameter

each of the different force levels the same characteristic held true, that is, percent penetration and nugget diameter, remained fairly constant until the first tip pickup, and thereafter rose to a new constant value. Ultimate shear strength appeared to rise continuously, leveling off after tip pickup. These typical characteristics are shown in Fig. 6.

Comparison of 4- and 10-in. Radius Dome Electrodes ($^5/_8$-In. Diam, No. 2 Morse Taper). With a water cooling temperature of 72° F, seven test runs were made with 4-in. radius dome electrodes, at 900 lb tip force. Three control runs were made with 10-in. radius dome electrodes for comparison. The results of these tests may be summarized as follows:

4-in. radius dome electrodes:
Average tip life, 41.0 welds
Average shear strength, 772 lb
Range of shear strength, 670–900 lb
Secondary weld current, 26,500 amp

10-in. radius dome electrodes:
Average tip life, 52.6 welds
Average shear strength, 760 lb
Range of shear strength, 550–880 lb
Secondary weld current, 27,400 amp

Average shear strength values include only those welds to the first tip pickup. In these tests, tip life was 22% longer with the 10-in. radius dome electrodes. It is not expected that the small difference in the ranges of shear strength between welds made with the 4- and 10-in. radius electrodes would change the tip life appreciably. It may also be noticed that less energy is required with the 4-in. radius electrode.

To determine if this characteristic holds true at another force a tip-life study was performed using 1050 lb tip force (determined optimum for longer tip life). Cooling water temperature for this test was 75° F. Summarized results are as follows:

4-in. radius dome electrodes:
Average tip life, 43.6 welds

Average shear strength, 730 lb
Range of shear strength, 480–960 lb
Secondary weld current 28,400 amp

10-in. radius dome electrodes:
Average tip life, 49.7 welds
Average shear strength, 745 lb
Range of shear strength, 540–950 lb
Secondary weld current, 30,300 amp

Once again, the 10-in. radius dome electrodes gave longer tip life but required more current than the 4-in. radiused electrodes.

Comparison of $^{7}/_{8}$- and $^{5}/_{8}$-In. Diam Electrodes (10-In. Radius Domes). Preliminary comparisons of $^{7}/_{8}$-in. diam (No. 3 Morse taper) electrodes in heavy-duty electrode holders with $^{5}/_{8}$-in. diam (No. 2 Morse taper) electrodes in standard holders, indicated that $2^{3}/_{4}$ gal of cooling water flowed through the electrodes while only 2 gpm flowed through the smaller electrodes. Tip-life studies were made with a cooling water temperature of 78° F.

Summarized results with 1050 lb. tip force are as follows:

$^{5}/_{8}$-in. diam electrode:
Average tip life, 43.0 welds
Average shear strength, 810 lb
Range of shear strength, 600–920 lb
Secondary weld current, 33,700 amp

$^{7}/_{8}$-in. diam electrode:
Average tip life, 57.8 welds
Average shear strength, 850 lb
Range of shear strength, 620–1020 lb
Secondary weld current, 33,700 amp

The $^{7}/_{8}$-in. electrode gave 25.6% longer tip life and required the same weld current. The longer tip life may be attributed to better electrode cooling.

This test has served to illustrate that longer tip life can be attained with a more efficient means of dissipating heat produced at the electrode tip. This fact instigated the desire for knowledge of the effect of external water cooling applied at the interface between the electrode and tip material.

Tip Life Studies with External Water Cooling. Temperatures of both the internal cooling water and the external cooling water were measured at 78° F during these tests. A tip force of 1050 lb was used with 10-in. radius dome $^{7}/_{8}$-in. diam electrodes.

Two test runs were made while water was being sprayed on the surface of the sheet material during welding. This was accomplished by manual operation of a paint spray gun. The results of these tests are as follows:

Average tip life, 146 welds
Average shear strength, 740 lb
Range of shear strength, 180–900 lb
Secondary weld current, 32,000 amp

A third test was made with $^{1}/_{64}$-in. holes drilled in the electrodes, from the dome to the water cooling hole, at an angle of about 45° from the vertical. This permitted water to flood the oncoming surface of the test specimens. Following are summarized results:

Average tip life, 140 welds
Average shear strength, 750 lb
Range of shear strength, 300–900 lb
Secondary weld current, 32,000 amp

Average tip life increased nearly 300% with external water cooling and no unusual weld characteristics were noted in these tests until after the first electrode began to alloy with the sheet material. Shortly after this first tip pickup, shear strength began to vary widely producing some "dud welds." Weld nuggets became unsymmetrical and in some cases only corona bonding occurred.

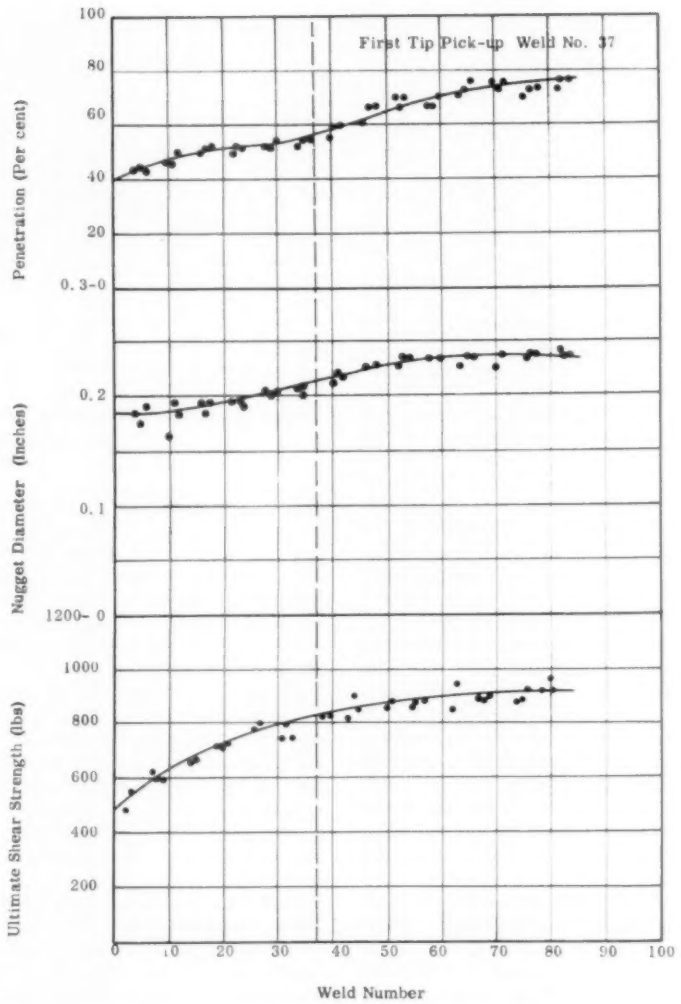


Fig. 6 Typical characteristics of percent penetration, nugget diameter and shear strength as a function of weld number

Discussion of Tip-Life Studies

For this material and the welding schedules used the results clearly indicated that the optimum performance of tip life was obtained at or near 1050-lb tip force. It was found that tip pickup is highly sensitive to all factors which influence the production of heat at the interface between electrode tip and work material. Small changes in any factor which affects this heat production may have large effects on tip life before pickup. In fact, the 5052 material used in these tests seems to be particularly sensitive in this regard, as compared with certain other aluminum alloy sheet materials. Electrode contour is another factor of prime importance in this regard. It was observed that early tip sticking was sometimes caused by small flats on the electrode dome. The electrode tip should be symmetrical, spherical and free from dirt and grease for optimum performance.

With the $^5/_8$-in. diam electrodes, a 10-in. radius dome proved superior to the 4-in. radius dome for longer tip life. However, the 10-in. radius dome required more energy per weld to produce the same shear strength. A possible explanation for the difference in energy requirements may be weld current densities. With a 4 in. radius, the contact area is somewhat less than with a 10-in. radius electrode. In order to have identical current densities a higher value of current would be required for the larger contact area.

In comparison of $^7/_8$-in. with $^5/_8$-in. diam electrodes, the larger electrode circulated more cooling water and provided a larger cross section of copper to conduct heat away from the electrode-sheet interface, with improved interface cooling. Naturally, longer tip life was obtained. Energy requirements to produce a desired nugget size are the same for both sizes of electrodes. However, at *identical welder control settings* the larger electrode holder drew about 1400 amp more current than did the smaller electrode because of its lower secondary resistance. Therefore, to produce identical shear strengths, it was necessary to reduce the heat control setting to obtain the selected secondary current magnitude.

As a result of external water cooling during welding, weld penetration appeared to be held under 50% of the sheet thickness. No change was noted in nugget diameter at the interface prior to the first tip pickup. After tip pickup occurred, nuggets became unsymmetrical and in some cases there was no nugget at all. It is expected that from 50 to 75 good welds, without tip pickup, could be produced routinely with external water cooling, as compared with about 45 welds without external water cooling.

As mentioned previously, tip pickup did not usually occur at the top and bottom electrodes at the same time. With exceptions, and depending on tip force, the first electrode to give tip pickup without external water cooling was usually between 30 and 50 welds and the second electrode between 50 and 80 welds. The reason for these inconsistencies has not yet been determined.

Metallographic examination of the sectioned welds indicated small amounts of porosity in the nugget. Variations of tip force, electrode contour and method of cooling showed no difference in the amount of porosity in the weld. Such nugget porosity might be eliminated by use of forge force in double-pressure equipment.

Electrode cooling-water temperatures in this research have varied with seasonal climatic conditions. This being an important factor in electrode cooling and believed to influence tip life considerably, comparisons of tip-life studies made at different water-cooling temperatures would not be justified. Cooling-water temperatures are listed for each tip-life study.

Conclusions

The data herein clearly suggest 1050 lb tip force and a 10-in. radius dome electrode for producing the longest tip life. Other than the possibility of electrode material characteristics, the primary factors that seem to influence tip pickup most are (1) production of heat at the interface between the electrode and tip material, and (2) electrode contour. Although external use of a liquid coolant might not be desirable in normal production welding of aluminum, indications are that a new and different means of cooling will be necessary for longer tip life, which may increase the problem of sheet surface deterioration.

The inconsistencies of tip life are unexplained. Variables of sheet surfaces resistance and welding schedules appeared to be well under control. Extreme care was taken in forming 4- and 10-in. radius domes on the electrodes, and still inconsistencies in tip life were obtained.

The choice between 4- and 10-in. radius dome electrodes would probably depend on the prevailing circumstances. While somewhat longer tip life is obtained with a 10 in. radius, it is at the expense of greater energy requirements.

Acknowledgments

The authors of this paper wish to gratefully acknowledge the cooperation of the following groups for their assistance in this research: the Aluminum Company of America for supplying aluminum alloy sheet materials; the Taylor-Winfield Corp. for supplying resistance welding equipment; the Diversey Corp. for supplying chemical cleaning materials; the Weltronic Co. for supplying a surface resistance indicator; the P. R. Mallory & Co. for supplying electrodes and electrode holder; the Welding Practices Subcommittee of the RWMA, for their technical guidance.

Experimental work was done in the research laboratory of the Department of Welding Engineering by Richard A. Davis and Robert L. Shively, together with other students in welding engineering, under the supervision of Robert C. McMaster and others of the staff in the Department of Welding Engineering.

APPENDIX—Commercial Quality Standards for Aluminum Spot Welds Used in Tip Life Studies

The following requirements for spot-welding aluminum alloy were used in this research:

1. Welding machine ram or arm should have minimum friction compatible with required accuracy of alignment.
2. Adequate flow of coolant is required through electrodes and welding secondary circuit in order to achieve welding consistency and adequate production rate and reasonable number of spots between required electrode dressing.
3. Cleaning of aluminum material (both degreasing and deoxidizing) is necessary in order to achieve reasonable weld quality and rate of production. This cleaning may be either chemical or mechanical. Contact resistance should be maintained below 50 micro ohms.

Appearance Defects

1. Electrode indentation—permitted to maximum of 20% of sheet thickness.
2. Surface cracks or cavities—none permitted.
3. Surface expulsion—none permitted.
4. Irregularly shaped welds—permitted but no multiple welds.
5. Expulsion between sheets—permitted to 5%.
6. Sheet separation—permitted to greater of 0.010 in. or 12% sheet thickness.

Internal Defects

1. Porosity—permitted.
2. Cracking—permitted.
3. Non-metallic inclusions—permitted.
4. Penetration—10 to 90% usually required to maintain consistency of weld strength with reasonable electrode life.

Weld Strength

Spot weld shear strengths are established at approximately 80% of values expressed in MIL – W – 6860.

Primary interest is in productivity and consistency. Maximum productivity will probably be achieved at the minimum shear strength at which consistency can be achieved.

LOCAL STRESSES IN SPHERICAL SHELLS FROM RADIAL OR MOMENT LOADINGS

Design information on deflections, bending moments and membrane forces, from radial loads and moments acting on a cylindrical attachment, and on the influence of simultaneous internal pressure

BY P. P. BIJLAARD

ABSTRACT. As a continuation of similar work on cylindrical shells, published in *Transactions ASME*[1] and in THE WELDING JOURNAL,[2, 3] design information is presented on the deflections, rotations, bending moments and membrane forces caused in spherical shells by radial loads and moments transmitted through a cylindrical attachment, such as a pipe. As a first approximation, which for most cases will be sufficiently accurate, it is assumed that the cylindrical attachment is absolutely rigid. It appears that, due to the relatively small deflections of a spherical shell, the influence of simultaneous internal pressure is much less than for a cylindrical shell. The published results were obtained as part of a research project on the effects of external loads on pressure vessels, jointly sponsored at Cornell University by the Bureau of Ships, U. S. Navy and the Pressure Vessel Research Committee of the Welding Research Council.

Introduction

Acting as an investigating, research and development agency for several code-making bodies and for many important power and processing industries, the Pressure Vessel Research Committee (PVRC) of the Welding Research Council devotes its entire resources in collecting and correlating existing information and in developing new information which can be used as a guide in establishing analytical and design rules together with fabrication and assembly procedures. This should lead to more economical use of all available metals in pressure vessels constructed with inherent safety.

Part of the PVRC's program is an investigation on the effects of external local loadings on pressure vessels, sponsored at Cornell University. Up to now considerable information has been obtained on the effects of local radial loads and external moments on cylindrical shells, with and without internal pressure, as published in References 1, 2 and 3. The present paper presents the first results obtained in determining these same effects for spherical vessels or spherical vessel heads. The radial loads or external moments are assumed to act upon a cylindrical attachment or pipe. As a first approximation, which for most cases will be sufficiently accurate, it is assumed that the pipe can be idealized as a rigid cylindrical insert, as sketched in Fig. 1 for a radial load P and in Fig. 7 for an external moment M. In subsequent papers the influence of the deformation of the attachment and that of reinforcing pads will be discussed. Poisson's ratio was assumed to be 0.3.

The results are presented in graphs, enabling the designer to read the required data. The derivations upon which these graphs are based are given in reference 4.

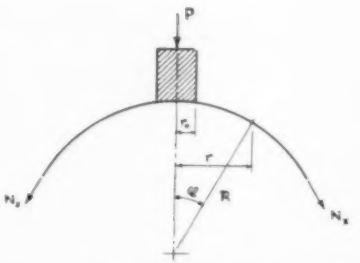


Fig. 1 Spherical shell subjected to a radial load P, acting upon a pipe considered as a rigid cylindrical body

Effect of a Radial Load

The data for the case of a radial load P, transferred by a pipe, considered as a rigid cylindrical insert (Fig. 1) are assembled in Figs. 2 to 6, where

- E = elastic modulus of shell material
- R = radius of curvature of middle surface of shell
- t = thickness of shell
- r_0 = outer radius of pipe
- r = distance of pertinent point of middle surface from axis of pipe
- w = deflection, considered positive if away from center of shell

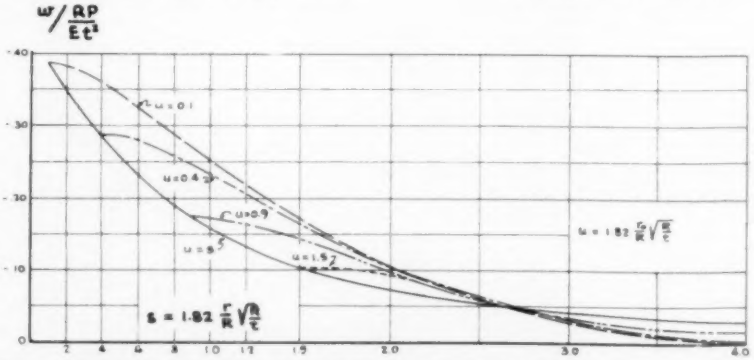


Fig. 2 Deflections of spherical shell subjected to radial load P

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The derivations upon which the design graphs in this paper are based are presented in Welding Research Council Bulletin No. 34, March 1957.

M_x = radial moment; acting per unit width upon a normal section, formed by the intersection of the shell wall with a conical surface with half top angle $\varphi = \sin^{-1}(r/R)$ (Fig. 1)

M_y = tangential moment; acting per unit width upon a meridional section, formed by the intersection of the shell wall with a meridional plane, passing through the axis of the shell (assumed in the axis of the pipe)

N_x = radial membrane force; acting per unit width upon a normal section, as defined above

N_y = tangential membrane force; acting per unit width upon a meridional section, as defined above

A moment is considered as positive if it causes compression at the outer surface of the shell. A membrane force is considered as positive if it is tensile.

In all graphs the deflections, moments and membrane forces are plotted versus the parameter s, as defined in the graphs. Since s is proportional to r, it defines the point of the shell to which the deflections, moments and membrane forces refer. On the other hand u, as defined in Fig. 2, and being equal to $(r_0/r)s$, defines the outer radius r_0 of the pipe. The solid curves refer to points of the shell where $u = s$, that is to points next to the pipe. The other curves refer to points of the shell where s is larger than u, so that r is larger than r_0. Hence these curves refer to points of the shell away from the pipe. For example, in Fig. 2 the curve $u = 0.4$ refers to a shell-pipe connection for which $u = 0.4$, so that at a distance $r = 2r_0$ from the pipe axis, where $s = (r/r_0)u = 2u = 0.8$, from Fig. 2 the deflection away from the shell center is $w = -0.26RP/(Et^2)$. From Figs. 4 and 6 the moments M_y and the membrane forces N_y away from the pipe may be larger than those at the pipe, but in general the most unfavorable combination of stresses in the shell occurs next to the pipe.

Example of Calculation. Let $R = 50$ in., $r_0 = 3$ in., $t = 0.5$ in. Determine the deflection and the stresses next to the pipe for a steel shell from a radial load $P = 1$ kip.

Solution: Next to the pipe $s = u = 1.82\,(r/R)\sqrt{R/t} = 1.82\,(3/50)\sqrt{50/0.5} = 1.092$.

From Fig. 2, for $s = 1.092$ and $u = s$, $w = -0.145RP/(Et^2) = -29P/E = -29\,(1/30{,}000) = -0.00097$ in.

From Figs. 3 and 4, for the same value $u = s = 1.092$, $M_x = 0.067\,P = 67$ lb-in./in. and $M_y = 0.0205P = 20.5$ lb-in./in.

From Figs. 5 and 6, $N_x = -0.113P/t$

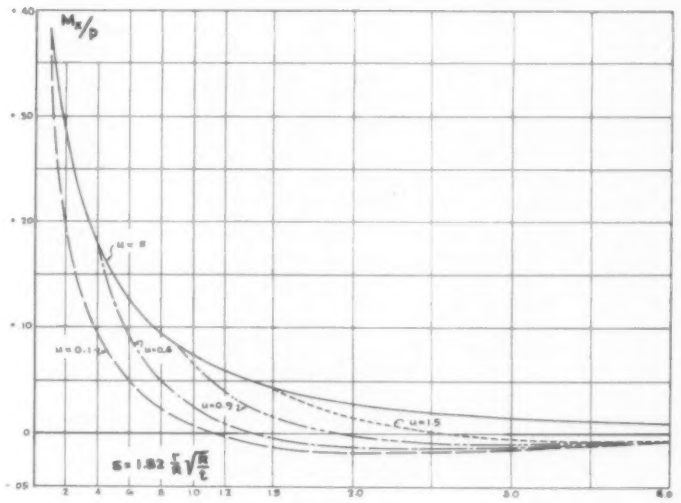

Fig. 3 Radial moments from radial load P

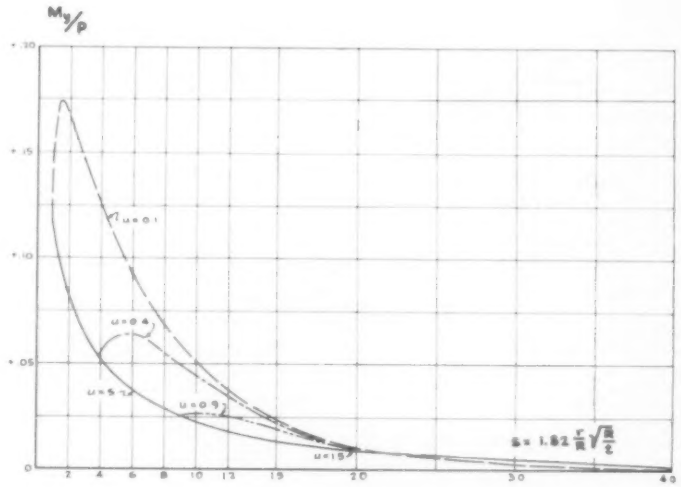

Fig. 4 Tangential moments from radial load P

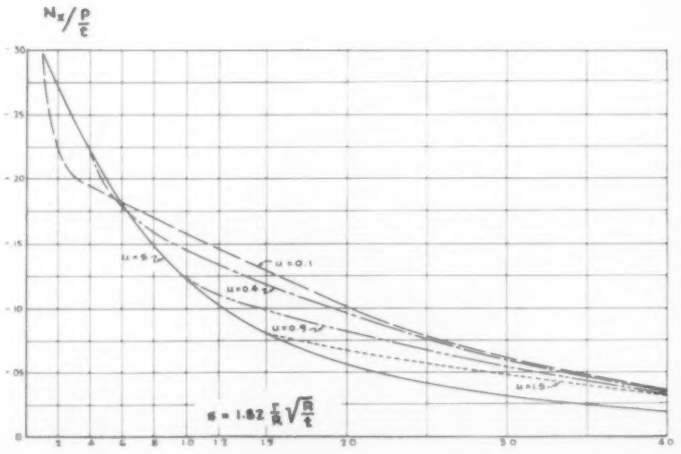

Fig. 5 Radial membrane forces from radial load P

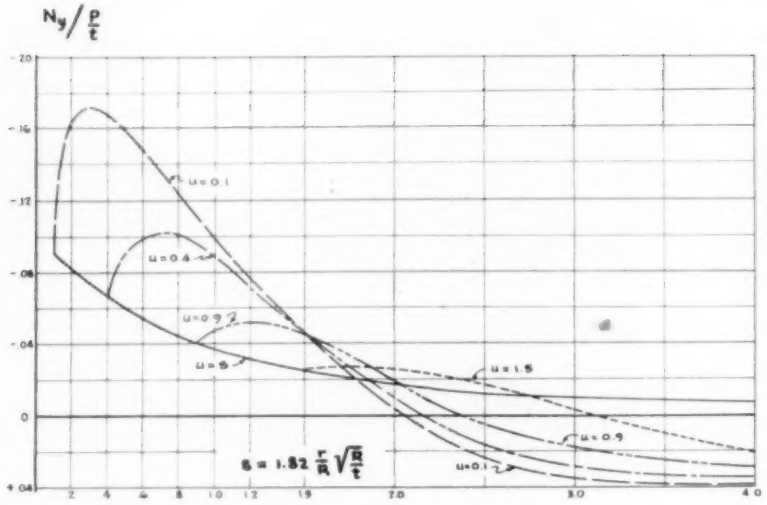

Fig. 6 Tangential membrane forces from radial load P

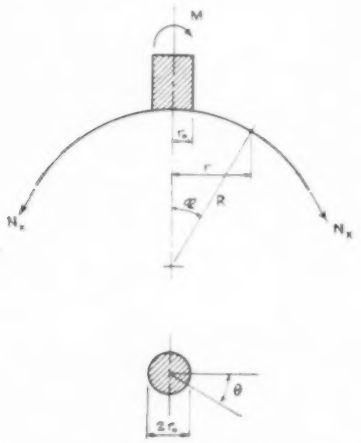

Fig. 7 Spherical shell subjected to an external moment M, acting upon a pipe considered as a rigid cylindrical body

$= -226$ lb/in. and $N_y = -0.034P/t = -68$ lb/in.

Denoting tensile stresses as positive, this leads to stresses $\sigma_x = (N_x/t) \pm (6M_x/t^2) = -452 \pm 1610 = 1158$ and -2062 psi and $\sigma_y = (N_y/t) \pm (6M_y/t^2) = -136 \pm 492 = 356$ and -628 psi, being equivalent to uniaxial stresses $\sigma_i = (\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y)^{1/2} = 1007$ and 1830 psi, at inner and outer surface of shell, respectively.

Effect of an External Moment

The case of an external moment M, transferred by a rigid pipe, is sketched in Fig. 7. The notations are similar to those for a radial load, but in the present case the deflections, bending moments and membrane forces are not only a function of the distance r from the shell (or pipe) axis, but also depend on the angle θ, shown in Fig. 7. The information pertaining to this case is assembled in Figs. 8 to 12, from which all values presented are proportional to $\cos\theta$, so that they obtain maximum or minimum values for $\theta = 0$ or 180°. For $\theta = 0°$, w, N_x and N_y are minimum (that is, maximum negative) and M_x and M_y are maximum. For $\theta = 180°$ all these values are equal and opposite to those for $\theta = 0°$.

Also here the solid curves refer to points of the shell next to the pipe, where $s = u$ or $r = r_0$. The other curves refer to points where r is larger than r_0.

Example of Calculation. For the same shell-pipe assembly as used for the case of radial load, the deflections and stresses next to the pipe and for $\theta = 0$ (Fig. 7) will be determined for an external moment $M = 1$ kip-in.

Solution: As in the preceding example next to the pipe $s = u = 1.092$. Then from Fig. 8, since $\cos\theta = \cos 0° = 1$, $w = -0.166\,(M/Et^2)\sqrt{R/t} = -6.64M/E = -6.64\,(1/30{,}000) = -0.000221$ in. This causes an *angle rotation* of the pipe in the direction of M (Fig. 7) of $-w/r_0 = 0.000221/3 = 0.000074$ radian.

From Figs. 9 and 10, for $s = u =$

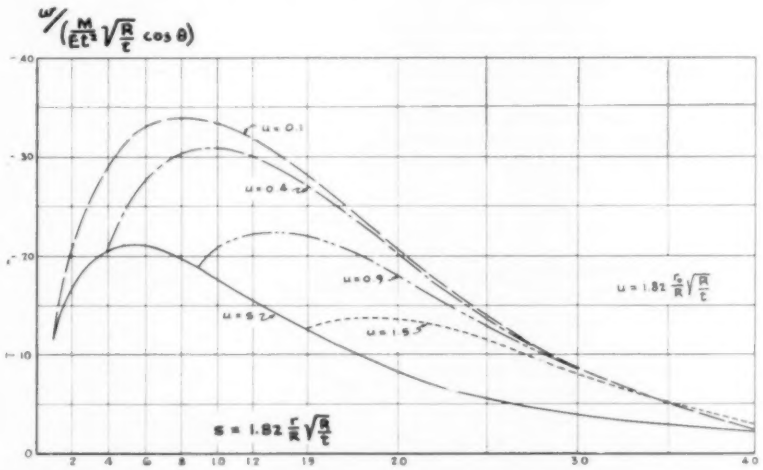

Fig. 8 Deflections of spherical shell subjected to external moment M

Fig. 9 Radial moments from external moment M

1.092, $M_x = 0.175\ (M/R)\sqrt{R/t} = 0.035M = 35$ lb-in./in. and $M_y = 0.056\ (M/R)\sqrt{R/t} = 0.0112M = 11.2$ lb-in./in.

From Figs. 11 and 12, for the same parameters, $N_x = -0.129\ (M/Rt)\sqrt{R/t} = -0.0515M = -51.5$ lb/in. and $N_y = -0.039\ (M/Rt)\sqrt{R/t} = -0.0156M = -15.6$ lb/in.

This leads to stresses $\sigma_x = (N_x/t) \pm (6M_x/t^2) = -103 \pm 840 = 737$ and -943 psi and $\sigma_y = (N_y/t) \pm (6M_y/t^2) = -31 \pm 269 = 238$ and -300 psi, being equivalent to uniaxial stresses of 650 and 835 psi, at inner and outer shell surface, respectively.

Influence of Simultaneous Internal Pressure

In contrast to cylindrical shells,[2] due to the relatively smaller and more localized curvatures caused by the local loading of spherical shells, the reduction of deflections and bending moments from simultaneous internal pressure is here relatively small. For a radial point load, for $R/t = 100$ and $R/t = 300$, the reduction of the maximum deflection by an internal pressure causing membrane stresses $\sigma_x = \sigma_y = 13{,}000$ psi, is only 4 and 11%, respectively. For a radial load acting upon a pipe (Fig. 1) with a parameter u (Fig. 2) = 0.1, for a shell with $R/t = 100$, the same internal pressure decreases the maximum deflection by 5% and the maximum moment M_x by 2%.

Acknowledgment

This investigation is part of a program carried out at Cornell University under the sponsorship and with the financial assistance of the Bureau of Ships, U. S. Navy, represented by J. L. Mershon, and the Design Division of the Pressure Vessel Research Committee of the Welding Research Council, Dr. E. Wenk, Chairman, and J. H. Drucker, Executive Secretary. The Advisory Committee for this project consists of J. J. Murphy, Chairman, and W. E. Cooper, J. N. Downs, H. Liessenberg, J. L. Mershon, V. L. Salerno, A. M. Wahl, D. B. Wesstrom, members.

The numerical data for obtaining the graphs were calculated from closed formulas, developed by the author, by J. D. Rutledge, graduate student, at the Cornell University Computing Center, on a CPC type IBM machine.

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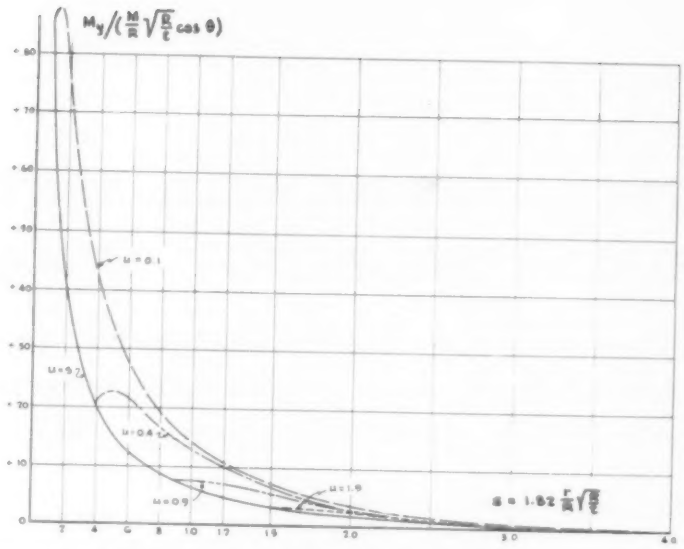

Fig. 10 Tangential moments from external moment M

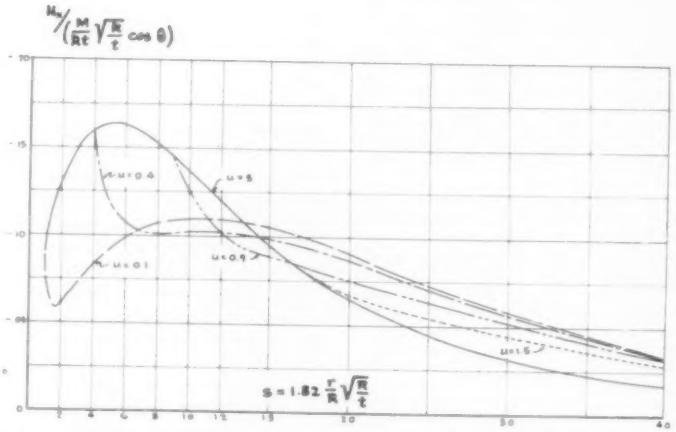

Fig. 11 Radial membrane forces from external moment M

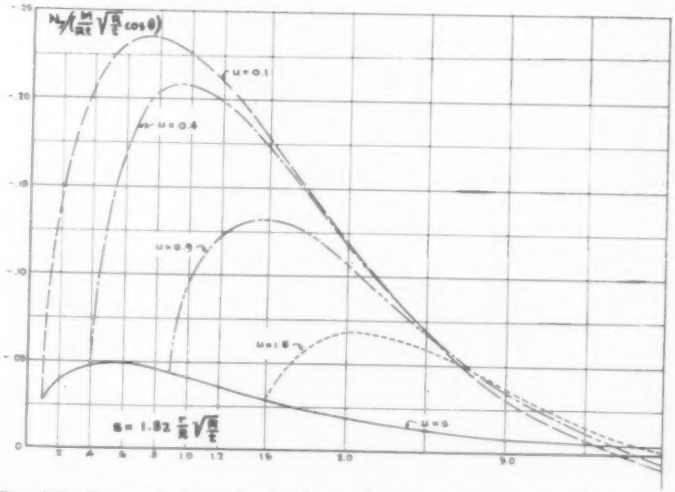

Fig. 12 Tangential membrane forces from external moment M

EVALUATION OF WELD-JOINT FLAWS AS REINITIATING POINTS OF BRITTLE FRACTURE

Influence of various types and sizes of flaws in welded butt joints on the initiation of brittle fractures studied under conditions closely simulating those found in service

BY D. C. MARTIN, R. S. RYAN AND P. J. RIEPPEL

ABSTRACT. A literature survey was made to determine the fundamental factors and circumstances that are known about brittle fractures in ship steels and similar materials. The survey was the initial part of this investigation for the Ship Structure Committee under the Bureau of Ships on the evaluation of flaws in weld joints. Various testing methods and specimens used in previous investigations involving brittle fracture were reviewed. Preliminary studies were made to determine the best method of introducing flaws into weld joints to simulate the flaws found in service failures.

A major portion of the effort on the project has been involved with determining: (*a*) what kind of test specimen and apparatus should be used to evaluate weld-joint flaws; (*b*) what kind of loading or types of loading are needed to simulate service conditions in ships or other large structures; and (*c*) what nominal stress is required to initiate a brittle fracture from large weld cracks and other flaws such as lack of weld fusion.

A significant result has been that brittle fractures initiate from weld defects in the laboratory specimen under conditions similar to the reported conditions involved in some service failures of ships.

Introduction

Previous extensive studies of many ship failures have shown that fractures frequently have initiated at various types of weld-joint flaws. Some of these weld-joint flaws have been located in areas of severe structural joints in plates located well away from major structural discontinuities. Although numerous investigations of the causes of brittle fracture in ships have been undertaken in the past 12 years, no extensive study has been made of the part that weld flaws play in initiating brittle fractures in welded structures. There is lack of knowledge concerning what types and sizes of flaws are potentially dangerous in a ship structure.

This investigation was advised by the National Research Council and sponsored by the Ship Structure Committee through the Bureau of Ships, Department of the Navy. The principal objective was to evaluate the influence of various sizes and types of flaws in welded butt joints on the initiation of brittle fractures. It was hoped that a study of such flaws under conditions that closely simulated those of service might aid in establishing adequate production, inspection and repair procedures for use in ship construction. The ultimate goal would be to aid the shipbuilder to eliminate potentially dangerous flaws from ships during construction.

The initial problem in this study was to select or devise a test specimen and a means of testing it by which flaws in welded joints could be tested under a variety of simulated severe service conditions. Since many other investigators of brittle fracture have faced this same problem, the first phase of this investigation was a study of the literature dealing with brittle fracture. This study was made to obtain background information and at the same time to search for a specimen and testing procedure that might be suitable for use in evaluating weld-joint flaws. This selected survey of literature was supplemented by discussions with several leading investigators in the field of brittle fracture in steels.

As a result of the survey and discussion, a test specimen and method of testing was devised by which it is believed that service conditions in large welded structures can be simulated. The testing apparatus is a sphere, approximately 9 ft in diameter, made from a high-strength low-alloy steel with good notch toughness. The test specimen is a 24-in.-diam circular disk of ship-plate steel, which is welded into and is part of the wall of the sphere. The test disk has the same thickness and contour as the wall of the sphere and contains full-size welded butt joints in which various welded flaws of controlled size are located. During testing, the entire sphere is cooled to a selected temperature and then loaded by hydrostatic pressure. After testing, the specimen is removed from the sphere wall, and a new specimen welded in place. Various schemes have been devised to complicate and concentrate the basic 1:1 ratio of biaxial tension stresses in the test panel, to simulate complex stress patterns and stress gradients in actual structures. In addition, tests have been made with the test panels subjected to cyclic loading.

A preliminary series of tests was conducted to determine the type, or combinations of loading conditions necessary to simulate service conditions. The results of these tests indicated that various weld defects could be evaluated by static load tests.

The test results described in this report have been made with $^3/_4$-in. Grade M Code Type E, modified ABS-B*, and ABS-B* steel specimens. The E and modified ABS-B steels were selected as the first materials to be tested because of their high transition temperature (80 and 100° F, respectively, at 15-ft-lb Charpy vee-notch).

Cracks and lack of fusion are the two types of flaws that have been evaluated in this investigation. The results of the present testing program indicate a correlation between crack length and the nominal stress required for fracture.

Summary

The following is a résumé of the

D. C. Martin and P. J. Rieppel are associated with Battelle Memorial Institute, Columbus, Ohio; R. S. Ryan was formerly with Battelle Memorial Institute but is now with Columbia Gas System Service Corp., Columbus, Ohio.

The views expressed are those of the authors and do not necessarily represent the views of the Ship Structure Committee or its member agencies.

* This refers to ABS-B requirements in effect before Jan. 31, 1956.

important findings so far obtained on this investigation.

With regard to the test technique:

1. The testing technique produced brittle fractures from weld flaws when tests were made at temperatures below the 15-ft-lb Charpy vee-notch transition temperature of the test plate being used.

2. Sufficient energy was stored in the test apparatus to propagate the fracture after it was initiated.

3. The fracture stopped or turned ductile and ran only a short distance after meeting the weld joining the test plate to the test vessel.

With regard to welds containing cracks or lack-of-fusion flaws:

1. Brittle fractures initiated from cracks which ended in the base metal without visible signs of ductility. Fractures initiated at nominal stresses well below the yield strength of the test plate provided the crack was 4 in. long or longer.

2. As the length of the crack increased, the nominal fracture stress decreased. An increase in crack depth decreased nominal fracture stress only slightly.

3. When weld cracks ended in sound weld metal, brittle fractures did not initiate. In some tests ductile fractures occurred.

4. The addition of residual or reaction stresses to the stress system in general lowered the nominal fracture stresses. In some cases, a brittle fracture initiated as a result of residual or reaction stresses alone, that is at zero nominal stress.

5. Brittle fractures initiated from lack-of-fusion flaws in welds. There was some decrease in nominal fracture stress with increase in length of flaw. There was a considerable decrease in nominal fracture stress with increase in depth of the flaw.

In general:

1. The data obtained did not indicate that cracks in welds were more serious flaws than lack of fusion.

2. The nominal fracture stresses obtained are much higher for small flaws than might be predicted by nominal stresses calculated to be present in structures which have failed. This indicates that the calculated nominal stresses in the structures may be lower than the stresses actually present in some areas in the structure by factors of 2, 3 or more.

Brief Review of Brittle Fracture Knowledge

An early investigation[1] of ship failures showed that there were several factors that contributed to the occurrence of brittle failures. They can be classified under three main headings: (1) design; (2) material; and (3) construction. Each of these three items have been improved since the early days of the accelerated program of mass-producing welded ships. It is now believed that defects built in during construction, sometimes resulting from poor workmanship, may be the major focal points of failure. This does not necessarily mean that such built-in flaws result from deliberate spoiling of work. As long as the welding process is controlled predominantly by the human element, defects will never be eliminated completely. These defects in the form of small nicks, cracks, and notches are built into the structure.[2] It would be desirable if the fabricator knew to what degree the flaws affect service performance of the weld joints so that intelligent decisions can be made as to which defects must be repaired and which may be tolerated.

It would not be too difficult to evaluate the effect of various weld-joint flaws if a simple laboratory specimen and testing method was available which simulated actual service conditions. Unfortunately, at the start of this investigation such a specimen and method were not available. This difficulty was first encountered about 10 years ago when the first major attempts were made to study brittle fracture. It became apparent that there was no single simple laboratory specimen, because the brittle fracture problem was too complex. A great deal has been learned, but the selection of a laboratory specimen for this study was still a difficult task.

The laboratory specimen selected for this investigation necessarily must simulate service conditions on a full-sized weld joint. In order to make this selection, it was necessary to consider: (1) the conditions present when brittle fracture occurred; and (2) basic facts which were known about brittle fracture. Prior to deciding on a specimen and test method, the available information was reviewed and is presented briefly in the following paragraphs.

Failures have occurred in ship sections subjected to low nominal stresses at temperatures between 20 and 40° F. A few failures have occurred at temperatures above 50° F but have not been so extensive or serious as the ones which occurred at lower temperatures. Fractures were of a brittle type and showed very little ductility, although material

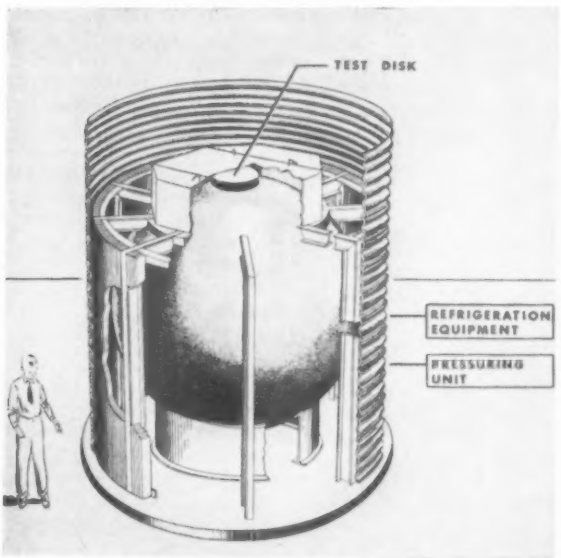

Fig. 1 Cutaway drawing showing testing apparatus and supplementary equipment

Fig. 2 Photograph of sphere beside enclosure

Table 1—Chemical Composition and Mechanical Properties of Disk Materials

	Chemical composition, %			Mechanical properties			
	Project steel E*	ABS-B steel†		Steel E*	ABS-B steel†	Modified ABS-B‡	Quenched and tempered high-yield-strength steel
Carbon	0.20	0.21	Yield strength, psi	30,950	30,700	33,000	114,000
Manganese	0.33	0.80	Ultimate strength, psi	58,430	59,400	59,500	122,000
Phosphorus	0.013	0.019	Thickness, in.	3/4	2/4	3/4	3/4
Sulfur	0.020	0.034	Elongation in 2 in., %	...	55.3	35	20
Silicon	0.01	0.04	Elongation in 8 in., %	30.6	31.7	...	...
Aluminum	0.009	0.003	15-ft-lb Charpy vee-notch transition temperature, ° F	80	40§	100§	−235
Nickel	0.15	0.10					
Copper	0.18	0.05					
Chromium	0.09	0.04	Tear test transition temperature, ° F	140	100	...	...
Molybdenum	0.018	0.01					
Nitrogen	0.005	0.005					
Vanadium	0.02	0.01					
Titanium	...	0.004					

* Klier, E. P., and Gensamer, M., "Correlation of Laboratory Tests With Full Scale Ship Plate Fracture Tests," Final Report, Project SR-96, Ship Structure Committee, Jan. 30, 1953.

† Ginsberg, F., Foster, M. L., and Imbembo, E. A., "Notch Toughness Properties and Other Characteristics of Medium Steel Ship Plate," New York Naval Shipyard Rept., Aug. 31, 1954.

‡ Modified by annealing at 1650° F and cold forming.

§ Transition temperature of cold-formed disks, tests performed at Battelle.

through which fracture occurred had normal strength and ductility in ordinary tests at room temperature.[3,4] The starting point of many fractures could be traced to a point of stress concentration at a notch resulting from structural or design details, welding defects, metallurgical imperfections, or accidental damage. Notches resulting from design details or welding defects were undoubtedly present in all ships of a given type. Research has shown that fractures originated only when high stress concentrations at critical locations in the structures or serious flaws occurred in combination with plates of unusually low notch toughness.[5]

The compositions of the ship steels investigated indicated that the notch sensitivity was increased by increasing amounts of carbon or phosphorus and decreased by increasing amounts of manganese. Notch sensitivity also was decreased by decreasing grain size. Silicon decreased notch sensitivity when added to perform the function of a deoxidizer and increased notch sensitivity when added as an alloying element.

It has been shown in tests of fractured plate[5] from ships that the plates in which fracture originated were generally more notch sensitive than the general run of plates used in ship construction. This was true using as the criterion of notch sensitivity either the 15-ft-lb transition temperature or the energy absorbed by Charpy vee-notch specimens at the failure temperatures of the respective plates.

Apparently, little energy is required to propagate the fracture once it is initiated, but the energy that is expended must be available at a minimum rate for propagating the crack. Fractures propagate at high speed. When the fracture is initiated, it progresses with increasing velocity until it approaches a maximum rate of about 5500 fps, which is related to the velocity of a transverse elastic wave in steel. The loud noise which has been reported for large fractures indicates an almost instantaneous release of a large amount of energy.[6]

Using the information obtained in the survey as a basis, specifications were set up to aid the selection of a laboratory test specimen and testing apparatus. The factors present in service failures, which the test method should provide were the following:

1. Stress patterns similar to severe conditions would include a certain degree of biaxial tension stress (possibly a 2:1 or 1:1 ratio) throughout the thickness of the plate. Superimposed on this would be flaws in welded joints to provide stress concentration and triaxiality.

2. Store sufficient elastic energy to propagate fractures at mean rates ranging from 1000 to 5500 fps.

3. An essential feature is that the fractures should be of the brittle type.

4. The fractures must pass through material subjected to low nominal stress levels of 10,000 to 20,000 psi. Provisions for higher stress levels should be available if needed.

5. Fractures should occur in the temperature range from 20 to 45° F. Lower temperatures should be available if required.

6. Fractures which initiate in weld-joint defects should propagate into the base plate of the test piece.

7. Material for test specimens should have a high Charpy vee-notch transition temperature. The plates should be selected from production quality of ship plate.

Development of a Specimen and Testing Method

The idea of inserting a test panel in a structure, such as a ship, and testing this panel under actual service conditions is obvious. However, if the panel failed, the whole structure would be in potential hazard. The sphere used as a testing apparatus in this investigation was devised from this idea. The apparatus is unique in that the sphere becomes a part of the test specimen after the disk is welded in. That is, the specimen is no longer a 24-in. disk but a 3/4-in.-thick specimen having a surface area of 275 sq ft. The sphere is sufficiently strong and notch tough at test temperatures to resist a fast-running fracture. In addition to static pressures, cyclic pressures can be applied to the structure. The diameter of the sphere is large enough to provide elastic energy to propagate fractures across the test panel at velocities ranging from 1000 to 5000 fps. The complete apparatus is described in detail in the next section.

Testing Methods

The testing apparatus is a 110 3/4-in. ID sphere made of 3/4-in. high-yield-strength alloy steel. The test plate, a 3/4- x 23-in. circular dished disk, is welded into the wall of the sphere. A sketch of the complete resting device which includes the testing apparatus, specimen, protective enclosure, lid, refrigeration unit, and pressuring equipment are shown in Fig. 1. A photograph of the sphere is shown in Fig. 2 with the enclosure in the background.

Sphere

The mechanical properties of the steel are given in Table 1.

Specimen

The disks were made of several types of steel of the quality used in ship construction: (1) Grade M, Code Type E; (2) modified ABS-B; and (3) as-received ABS-B. Grade M, Code Type E steel has low notch toughness. The modified ABS-B steel was heat treated to raise its Charpy vee-notch transition temperature to approximately that of the Type E steel. The as-received ABS-B steel is a standard material used in ship construction. It is less notch sensitive or has a lower notch transition temperature than the other two steels. The chemical and mechanical properties of the steels are shown in Table 1.

Disks for test specimens, 24 in. in diameter, were cut from the plates and formed to match the curvature of the sphere.

Flaws

The flaws were placed in butt welds or simulated butt welds in nearly all tests. Two types of flaws were used, cracks and lack of penetration. Cracks were made by placing cast iron in the weld joint when making the weld in the test specimen. Lack-of-fusion flaws were made by laying a $^1/_8$-in.-thick plate along one of the surfaces of the groove in which the flawed weld was made. This prevented fusion of the weld metal to the face of the groove and simulated a lack-of-fusion flaw. Both types of flawed welds were made in a jig to preserve proper curvature in the test specimen. A 14-gage steel disk was welded to the back of each test specimen. This disk acted as a diaphragm and prevented leakage through full-depth flaws.

Supplementary Equipment

Additional equipment was necessary to enclose the sphere, cool the specimen, and apply pressure to the sphere.

A protective enclosure was installed to prevent any possible damage in the event the sphere should break open. Experience at Battelle in bursting large-diameter pipe has shown that wood alone will not contain the escaping liquid when pressures are very high. On the basis of this experience, the enclosure was built to withstand the worst situation. The enclosure is an 11-ft-diam, $^1/_4$-in.-thick pipe made of several plates of corrugated steel. The 11-ft pipe is assembled from sections and bolted together. Steel-wire rope is bolted together with U-bolts around the outside of the pipe in the grooves, to provide additional protection. The inside of the enclosure is lined with 2 x 4-in. lumber to provide an insulating material between the cold sphere and room temperature and to provide a shock absorber between sphere and enclosure. A 6-ft octagonal lid made from $^3/_4$-in. plate is placed over the lid and secured to weights on the floor by means of cables.

Cooling is obtained from a coil in the test sphere, as shown in the sketch of a cross section in Fig. 3. Brine solution is used to fill the sphere and relatively uniform temperatures are obtained by circulating the brine. Temperatures as low as 0° F can be reached in the test plate.

Test plates are stressed by hydrostatic pressure, which produces biaxial tension stresses in the sphere wall. Pressures are obtained with an air-driven high-pressure water pump.

Testing Procedure

The test disk containing a flawed weld was welded into the sphere with low-hydrogen electrodes (AWS E100-16). The sphere was filled with brine and all air was removed. After the temperature of the sphere and disk was reduced to testing temperature, the sphere was loaded by hydrostatic pressure. A 100-psi increase in pressure results in about a 3700-psi increase in nominal stress in the sphere wall. The pressure in the sphere was increased until the disk fractured or until a pressure of 900 psi (33,000 psi nominal stress was reached. Strain measurements were taken at each 100-psi increase in pressure.

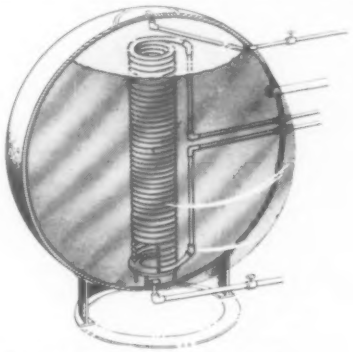

Fig. 3 Cross section of sphere

The testing temperatures were chosen in most tests to be equivalent to those at which the Charpy vee-notch energy value for the plate being used was 2 to 6 ft-lb. The tests in E steel and the modified ABS-B steel were made around 20° F and in the as-received ABS-B steel around 10° F.

The nominal stress in the sphere at fracture was in most cases determined from the pressure measurement using the equation $S = PD/4t$. There was good correlation between this calculated stress and that measured by strain gages placed on the sphere and disk away from the flaw. The nominal stress required to initiate a brittle fracture has been the major criterion used to evaluate and compare test results. Throughout this paper this stress will be referred to as the nominal fracture stress.

In only a few of the tests made was the nominal stress raised above 33,000 psi. Generally, if fracture had not occurred at 33,000 psi, loading was stopped. There were two reasons for this. One was that at nominal stresses above 33,000 psi the test plate began to bulge and the stress conditions in the plate changed radically. This was the major reason for stopping. A second reason for stopping at 33,000 psi was to protect the test equipment.

Fig. 4 Crack in both root passes of a double-vee butt joint welded with E6020 electrode

Subsequent passes welded with E6010 electrode. Nital etch. X 5. (Reduced by ½ upon reproduction.)

Influence of Flaws in Welds of Initiation of Brittle Fracture

Studies of the influence of weld flaws on the initiation of brittle fracture in mild steel plates were made using cracked welds and welds containing lack of fusion. Cracked welds were studied first since this type of flaw appears to be more severe than other types.[7,8] Consistent results were obtained in making cracks by laying a cast-iron rod in the joint and welding over it with an E6020 electrode. If further welding was done in the joint, E6010 electrodes were used. A crack made by this method in the root passes of a double-vee joint is shown in Fig. 4.

Influence of Cracks in Welds on Initiation of Brittle Fracture

Four types of cracked welds were used. Sketches of cross sections of each of these types are shown in Fig. 5. Seventy-nine plates containing cracked welds were used. Of these 30 contained Type A cracks, 3 contained Type B

cracks, 18 contained Type C cracks, and 28 contained Type D cracks. Most of the data discussed in this paper were obtained from test specimens containing Type A or Type D cracks.

In considering the physical attributes of a crack that might influence fracture initiation, length and depth were the ones obviously controllable. Other factors, for example the sharpness of the ends of the crack also would influence the behavior of the flaw, but it was believed that only length and depth could be controlled with any degree of assurance.

Early in the work, it was decided that in general the cracks being used as flaws should not end in weld metal. This decision was based on the known low Charpy vee-notch transition temperature for the weld metals used in the flaws. It was hoped that the cast iron used to crack the welds would raise the brittle transition temperature, but consistent behavior could not be counted on. The crack end being in the base plate assured that material of comparable brittleness was involved in fracture initiation in each test. Some of the anomalous test results discussed later are believed to have been caused by the crack end not being in the base plate.

Effect of Test Temperature

When test work was started, it was decided that tests should be made at temperatures between the 5-ft-lb and 10-ft-lb Charpy vee-notch temperatures for the base plate. This decision was made to try to insure that the test plates would act as "start" plates. In the course of the investigation, a number of tests were made on specimens containing an 8-in. Type A crack in E and modified ABS-B steel at temperatures from 12 to 34° F. Brittle fractures initiated in all of these tests. Over the temperature range tested, there seems to have been only a slight increase in the nominal fracture stress as the temperature was increased. This is shown in Fig. 6. In the 10 to 40° F temperature range, the Charpy vee-notch value for these steel varies from 3-ft-lb (10° F) to 7 ft-lb (40° F).

When tests are made on both sides of the Charpy vee-notch 15-ft-lb temperature, different results are obtained. Using a Type D notch, ABS-B steel, and temperatures at, below, and above the Charpy vee-notch 15-ft-lb temperature, the results shown in Fig. 7 were obtained. The results of all of the tests made indicated that as long as testing was done in the Charpy vee-notch 5- to 10-ft-lb temperature range, variations in temperature would not affect results appreciably. However, the results of tests at 15-ft-lb Charpy vee-notch temperatures and higher could not be compared with those made at the lower temperatures.

Effect of Crack Length

Length is the dimension of a weld crack that can vary most widely in a structure. Therefore, it seemed important to determine the effect of crack length on the initiation of brittle fracture. Initial tests were made on specimens containing what were thought to be serious flaws. These were Type A cracks (Fig. 5) 8 in. long. Brittle fractures initiated from these flaws at nominal shell stresses well below the 33,000 psi yield strength of the test plate. The results of these tests indicated that the test method worked and a study of the effect of crack length was undertaken. At first, tests were made on rather short cracks, and then during the course of the project, the range of crack lengths was expanded until a range of 1 in. to 16 in. was covered.

Figure 8 is based on tests made with Type A and Type D cracks. Data obtained from these tests are used since they represent the majority of the tests made. Only three tests were made with Type B cracks. The results of tests made with Type C cracks will be discussed later.

It was mentioned earlier that it was decided to end all cracks in base plate. Some tests were made to determine the effect of having the crack end in sound weld metal. For these tests, the test plate was cut in two and welded back together using a double-vee weld. Cracks of desired depth and length were made in this double-vee weld. Tests were made on disks containing cracks from 8 in. long to 16 in. No brittle fractures initiated in any of these specimens. In tests with 12- and 16-in. cracks, a fracture ran across the weld to the heat-affected zone, propagated a short distance along the heat-affected zone of the weld and stopped. In all of these, there was evidence of considerable deformation along the path of the fracture.

Only one test shown in Fig. 8 falls outside the band. This is the test with a 4-in. crack which failed at a nominal stress of 12,000 psi. No reason for this result has been discovered. With the exception of this test, the relationship between crack length and nominal fracture stress seems fairly consistent, although the scatter band is rather wide. The reason for this wide band may be that crack depth, test temperature, and type of base plate were ignored in drawing the figure. It is believed that of these, crack depth is most important in causing scatter since all tests were made at temperatures which were well below the 15-ft-lb Charpy vee-notch temperature of the plate material used.

Effect of Crack Depth

The effect of crack depth is shown in

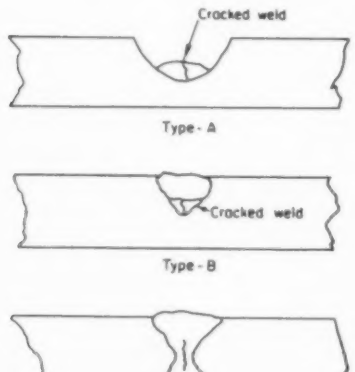

Fig. 5 Types of cracked welds used

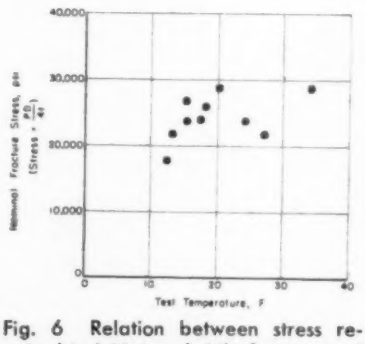

Fig. 6 Relation between stress required to initiate a brittle fracture and test temperature for cracks 8 in. long

Type A crack in E steel and modified ABS-B steel. Charpy vee-notch values range from 3 ft-lb at 10° F to 7 ft-lb at 40° F for both types of steel.

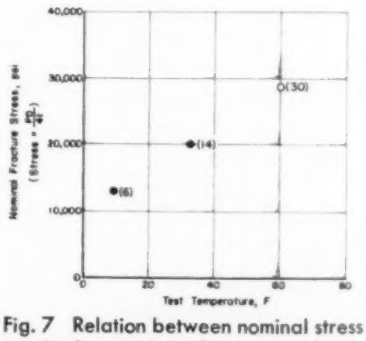

Fig. 7 Relation between nominal stress required to initiate fracture and test temperature for Type D cracks 12 in. long, ¾ in. deep, in ABS-B steel

Fracture at 60° F was ductile, others were brittle. Figures in parentheses are Charpy vee-notch values for the plate at the temperature of test.

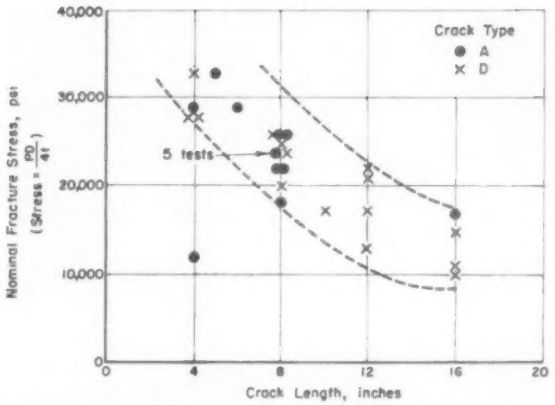

Fig. 8 Relation between length of crack and nominal stress required to initiate brittle fracture

In stress formula, P = pressure, D = diameter of sphere and t = thickness of plate.

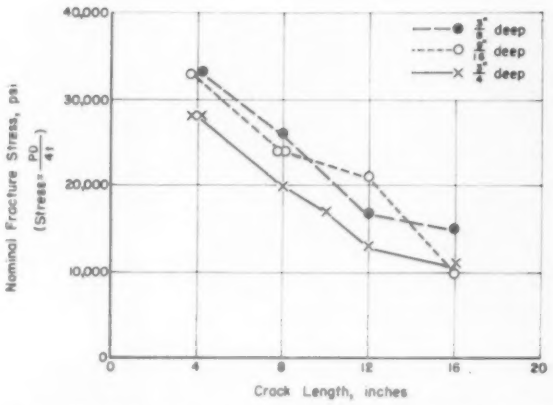

Fig. 9 Relation between crack length, crack depth and nominal stress required to initiate brittle fracture

Fig. 9. This figure shows that apparently crack depth does have some effect, although much less than crack length.

It will be noted that there are no points shown on either Fig. 7 or Fig. 8 for cracks less than 4 in. in length, although tests were made on plates which contained shorter cracks. However, none of these plates failed in test. In fact, two tests were made on specimens containing 4-in.-long cracks in which brittle fractures did not initiate at 33,000 psi. It appears that for this test 4 in. is about the limiting length of crack which will initiate fractures at nominal stresses below the yield strength of the test plate.

Even at 4 in. the crack had to be open to one surface or the other of the weld in the test plate for fracture to initiate at nominal stresses below 33,000 psi. A number of tests were made on plates containing Type C flaws which in general contained sound weld metal over both top and bottom of the crack. Cracks from 4 to 16 in. in length were used in these tests. In only two tests did brittle fractures initiate from Type C cracks. In one of these tests, a groove was ground $^1/_8$ in. deep in the weld over the 10-in.-long crack after the test plate had been taken to 33,000 psi nominal stress without failing. On reloading, a brittle fracture initiated at 31,000 psi nominal stress. In the second test, the 4-in.-long crack opened up during loading to the top surface of the weld. It thus became a type D crack of unknown length. The brittle fracture initiated at 18,000 psi nominal stress.

A number of the plates containing Type C flaws started to leak through the flaw at nominal stresses between 25,000 and 31,000 psi. This, of course, stopped the test.

Effect of Cyclic Loading

Early in the experimental work on this project it was suggested by the Project Advisory Committee that the stresses required to initiate brittle fractures were too high. That is, they were higher than the apparent service experiences of various types of welded structures would have predicted. Changes were made in the test procedure to attempt to reduce the magnitude of the nominal stresses required to initiate fracture. One of the changes was to use cyclic loading rather than uniform loading during the test. The results of tests made with cyclic loading are shown in Table 2. In one test, the crack opened up during cycling and the test had to be stopped because pressure could not be held. In the other tests, after cycling, the test plates were loaded to a higher stress than had been used in cycling. In two tests, the higher nominal stress used was in the range that should have initiated a brittle fracture from the type and length of crack used. Fractures did not occur in these tests. This indicated that cyclic loading did not reduce the nominal stress required for fracture. Consequently, no further tests were made using cyclic loading.

Effect of Residual Stresses

A second change that was introduced into the test procedure to try to reduce the nominal stress required to initiate brittle fracture was to try to supplement the pressure stress. In most of the tests made, the supplementary stresses were residual or reaction stresses imposed on the weld containing the flaw by other welds. Figure 10 shows a test plate which contained residual or reaction stress prior to testing. The two curved welds were used to produce these stresses. They were put in after the test disk was welded into the sphere.

One problem with such test plates was the difficulty of measuring the stresses imposed by the supplementary welding. The temperatures developed by the welding generally put the strain gages used out of commission. Consequently, in most of the tests, the magnitude of the residual or reaction stresses was not known. The results of the tests are plotted in Fig. 11. These results show that residual or reaction stresses of varying amounts were produced. These stresses were high enough in three cases to initiate brittle fractures from 8-in. cracks without pressure stresses being added.

Influence of Lack of Fusion in Welds on Initiation of Brittle Fracture

In a number of structural failures, lack-of-penetration flaws have been found to be the apparent cause of brittle fracture initiation. In this investigation, lack of fusion was substituted for lack of penetration. This was done because the size (length and depth) of a lack-of-fusion flaw could be controlled more easily than could lack of penetration. A sketch showing the method of making a lack-of-fusion flaw is shown in Fig. 12.

Table 2—Summary of Cyclic-Loaded Test

Flaw			Nominal stress, psi			
Type	Length, in.	Depth, in.	Cycling range	Maximum	No. of cycles	Results
A	8	$^9/_{16}$	11,000–20,000	20,000	200	Crack opened up
A	8	$^9/_{16}$	11,000–22,000	27,500	50	No failure
A	8	$^9/_{16}$	3,700–20,000	25,700	1000	No failure
C	8	$^9/_{16}$	9,000–20,000	24,000	1000	No failure

Fig. 10 Test plate which was designed to contain residual or reaction stresses prior to testing

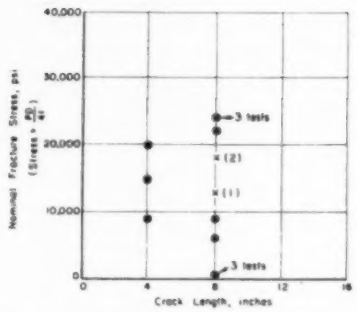

Fig. 11 Comparison of results of tests in which an attempt was made to introduce residual stresses at the flaw

Normal stress required to initiate brittle fracture with 8-in. crack was 24,000 psi; with 4-in. crack, 30,000 psi or higher without residual stresses. (1) Measured residual stress = 13,000 psi, (2) measured residual stress = 11,000 psi.

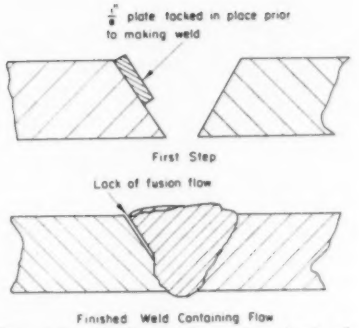

Fig. 12 Method of making lack-of-fusion flaw

The results of tests made with lack-of-fusion flaws are shown in Fig. 13. There does not appear to be a definite relation between nominal fracture stress and length of flaw. This is in contrast to what was found for cracks. There does, however, appear to be a relation between nominal fracture stress and depth of flaw. At least there is a definite tendency for brittle fractures to initiate from the deeper flaws at lower nominal stresses than from the shallow flaws. Also there were three tests made with 3/8-in. flaws in which a fracture did not initiate, even though two of these flaws were 12 in. long.

Discussion

It has been pointed out in the past that the evidence obtained from ship failures and other structural failures indicated that in numerous cases failures had started from small weld flaws at low nominal stresses. Stresses of 15,000 psi and lower have been mentioned. The most striking feature of the results obtained during the course of this project is that they do not correlate with this previous experience. If it can be assumed that a 4-in. crack qualifies as a small flaw, the data presented in previous sections show that a nominal stress of 30,000 psi or more is required to initiate a brittle fracture from such a flaw. In a number of cases, fractures were not initiated at stresses equal to the yield strength of the plate. Even with 8-in. cracks, nominal stresses of 20,000 to 25,000 psi were required to initiate brittle fractures.

That the specimen in the test used is the whole sphere and not just the 24-in.-diam test plate has already been discussed. It is believed that this specimen is large enough to give a valid indication of what would happen in a large structure containing the same type of flaw. In addition, the nominal stresses in the sphere are biaxial tensile stresses. This simulates the stress pattern present in a ship, particularly in the deck. Consequently, the behavior of the sphere should simulate the behavior of a part of a ship deck.

It should be pointed out that the behavior of the test specimen (the sphere) is similar to that of a ship except for the nominal stress required to initiate fracture. When a test plate containing a flawed weld is welded into the sphere, cooled to some temperature below the brittle transition temperature of the test plate, and loaded to some stress below the yield stress of the test plate, a brittle fracture initiates. This fracture initiates at the end or ends of the flaw (crack) where it enters the base plate. It starts in a material having a high transition temperature, runs as a brittle fracture until it reaches material which has a transition temperature below the test temperature. The fracture then either stops or turns into a ductile fracture which stops in a short distance. If the nominal fracture stresses which have been measured for 4-in. cracks were lower, the correlation with ship behavior would be excellent.

Part of the reason for the discrepancy between the measured values of nominal fracture stress and expected fracture stress may be contained in the data shown in Fig. 11. Here are tests in which fracture initiated at a low nominal stress. In fact, here are tests in which a brittle fracture initiated from an 8-in. crack at a nominal stress of 0 psi. Even a 4-in. crack initiated a brittle fracture at 9000 psi nominal stress. The reason for these results is, of course, the supplementary stresses (residual or reaction) which were imposed by the additional welding done on these test plates. The results of these tests indicate that initiation of brittle fractures in steel structures at low nominal stress (15,000 psi and below) may be due to the presence of residual or reaction stresses in the structure which are not considered in calculating nominal stress levels. It is quite possible to conceive of such stresses being equal to the yield strength of the steel. Such stresses would not be serious as long as the structure operates under conditions which permitted the steel to behave in a ductile manner. But conditions might change and become such that the steel would behave in a brittle manner. Then, the residual, reaction, or other stresses, combined

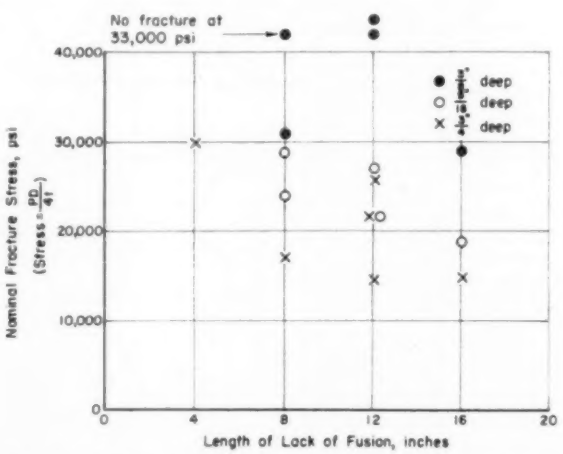

Fig. 13 Relation between length of lack-of-fusion flaw and nominal brittle fracture stress

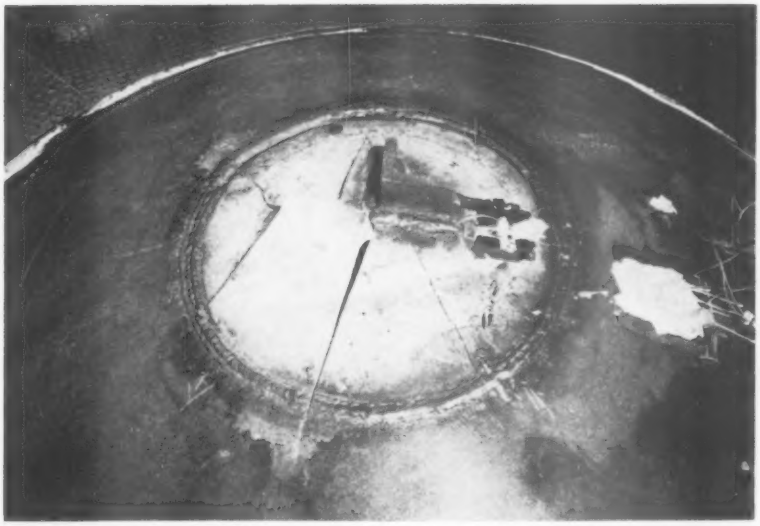

Fig. 14 Test plate containing structural detail. Appearance after test

with the stresses imposed by normal loading could be high enough to initiate brittle fractures from small flaws in the structure.

One test has been made which indicates the effect of a structural discontinuity. The test plate is shown in Fig. 14. A heavy angle with 4-in. legs was welded through the test disk. Full penetration welds were used on both sides of the angle. One weld was cracked full thickness while the angle was being welded in. A brittle fracture initiated from this crack at a nominal stress of 20,000 psi. In other tests, nominal stresses of 30,000 psi and higher were required to initiate brittle fractures from 4-in. cracks. The results of this test indicate that stress concentration caused by structural details also can cause brittle fractures to initiate at lower nominal stresses than would be expected from the data shown in Fig. 8.

A factor which has not been studied directly in this investigation but which may influence the initiation of brittle fracture in a structure is the sharpness of the end of the flaw. It may be that the sharpness or condition of the end of the cracks causes the scatter shown in Fig. 8. This factor might also influence the behavior of lack-of-fusion or lack-of-penetration flaws. The lack-of-fusion flaws should be less severe than cracks of the same length and depth since they should tend to be less sharp and therefore less severe. Comparison of Figs. 8 and 13 do not bear this out. In general, some nominal fracture stresses were obtained with lack-of-fusion flaws which were just as low as those obtained for cracks of equivalent length.

Future Work

It was mentioned earlier that no brittle fractures had been produced from crack flaws less than 4 in. long. The reason for this was the decision to stop loading when the nominal stress reached 33,000 psi. However, brittle fractures have initiated from smaller flaws in structures. Therefore, it appears that the next step in the research program is to characterize the conditions required to initiate brittle fractures from flaws smaller than the 4-in. cracks. The work already done with supplementary stresses (residual or reaction) suggest a way to study the influence of small flaws on brittle fracture initiation. Supplementary stresses may be added by welding or mechanical means. It also may be advisable to investigate the effect of structural details. It will be necessary regardless of the method used to measure the supplementary stresses with a reasonable degree of accuracy.

Lack-of-penetration flaws similar to those found in welded structures also should be investigated. It will be necessary to devise a method of producing this type of flaw with some consistency. The results of such tests can be compared with the results of tests on cracks and lack-of-fusion flaws to determine which are the most serious.

Acknowledgment

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FACTORS AFFECTING THE TENSILE PROPERTIES OF STEEL WELD METAL

Literature review emphasizes that, on the basis of its tensile properties, weld metal compares to cast steel in some respects and to wrought steel in others

BY C. M. WAYMAN AND R. D. STOUT

SUMMARY. The tensile properties of carbon-steel weld metal compare to cast steel in some respects and to wrought steel in others. For a given chemical composition, weld metal is usually stronger and less ductile than cast or wrought steel, and its yield-tensile ratio is significantly higher. At high temperatures, weld metal experiences a ductility trough in the interval 900 to 1100° C; this effect is peculiar to a cast steel. At less than 900° C, and to temperatures below room temperature, the tensile properties of weld metal show a trend comparable to that of a wrought steel. There is good evidence to indicate that weld-metal tensile properties are essentially independent of the welding process for welds of similar composition.

Structural defects that detract from desirable mechanical properties in weld metal include a coarse-grained, dendritic structure, segregation, inclusions of oxides, nitrides, and slag, porosity, fisheyes or haloes, and microcracks. With the exception of a coarse dendritic structure and segregation, most of these deficiencies can be eliminated by a suitable choice of welding process, materials and technique.

The effect of alloying elements on the hardenability of weld metal are much the same as in wrought steel. Additions of alloying elements have been correlated with the degree of fissure formation. Of the common elements, Mo seems to be the most desirable and Mn the least desirable for retarding fissure formation; slight amounts of Cr and V are beneficial, while Ni has no apparent effect. Carbon also plays a role in fissure formation. There is also evidence to suggest that alloying elements affect the solubility of nitrogen and distribution of nitrides in weld metal.

Nitrogen, when present in amounts greater than 0.02%, embrittles weld metal. The distribution of nitrogen whether present as needles or massive nitrides also affects the strength-ductility characteristics; nitride needles appear to be more significant in decreasing ductility. It is also believed that nitrogen as well as hydrogen contributes to fissure formation in welds, but the influence of nitrogen is less pronounced. Contrary to past belief, there is evolution of nitrogen upon solidification and cooling.

Oxygen also detracts from weld metal ductility, but is generally not present in significant quantity unless bare rod welding in an air atmosphere is practiced. It has been stated that oxygen causes embrittlement by the solution and subsequent precipitation of compounds. Oxide inclusions are also undesirable.

Hydrogen is also known for its embrittling action, which is most evident following rapid cooling of the weld metal. The exact nature of hydrogen embrittlement is not clear, and it is possible that several mechanisms may be at play, simultaneously or separately. The embrittlement caused by hydrogen may not be revealed in the conventional yield and ultimate strengths; its effects are more evident in bending or in measurements of tensile ductility. The low-hydrogen electrode, inert-gas-shielded metallic-arc, and submerged-arc methods produce deposits that are comparatively low in hydrogen.

High quantities of sulfur, above those usually met in practice, can cause weld metal embrittlement; the effects are significant above 0.07%. In general, sulfur acts more deleteriously by promoting porosity in the presence of hydrogen. Sulfur is best controlled by the use of basic fluxes or slags. Although the base metal may be nominally low in sulfur, regions of segregation can contain critical amounts of this element.

Phosphorous has a segregating tendency like that of sulfur, and high contents are more likely to occur in weld metal when reducing conditions prevail. It has been stated that quantities up to 0.128% do not affect tensile ductility.

Unless dilution is excessively high, the mechanical properties of sound weld metalare essentially independent of the base metal composition. High-sulfur base metal, or base plate that has not been fully deoxidized, can promote porosity as a result of H_2S or CO gas voids. Incompletely deoxidized base metal usually yields weld metal inferior in strength and ductility.

The type of steel used for electrode core wire has no significant effect on weld-metal mechanical properties, since changes in strength and ductility are usually effected by altering the electrode coating. Low-hydrogen deposits compare with cellulosic or non-low-hydrogen deposits in strength and ductility. High-alloy deposits have shown a tendency for stress-relieving embrittlement, but this has been overcome by a suitable choice of alloying elements to give the desired strength in the weld.

Divergent thoughts exist regarding the effect of welding technique on weld metal properties. High travel speeds may yield a deposit contour with an unfavorable stress distribution, but excessive speeds seem to have little effect on weld-metal ductility. Longer arc lengths promote higher weld metal nitrogen content. Energy input can affect the strength and ductility of the weld metal and the arc transfer efficiency of elements. High currents may be beneficial in view of the attendant annealing effect, but can give rise to serious porosity. If base metal impurity pickup is detrimental, joint buttering or cladding is a suitable remedy.

The solution of interstitial gases, O_2, N_2 and H_2, is controlled to a large degree by the shielding envelope around the weld metal as it solidifies. The carbon-dioxide shielding process produces weld metal that compares metallurgically to metal cast in helium or argon atmosphere. In inert shielding gases, the presence of excessive percentages of oxygen may lower the arc-transfer efficiency of the common alloying elements and give rise to erratic arc characteristics. Without a suitable shielding medium, oxygen and nitrogen absorption is excessively high. There is an indication that the atmosphere produced by low-hydrogen (E6016) electrodes does not exclude contaminants.

Since weld metal is generally a low-carbon steel with abundant free ferrite, strain aging occurs under promoting conditions. The deoxidation practice for the base plate seems to have no effect on the strain-aging tendency of welds, and low-hydrogen electrode deposits are in effect the same as others in susceptibility to this phenomenon. There is evidence to suggest that nitrogen alone is not responsible for strain aging in weld metal.

The effect of residual stresses resulting from solidification shrinkage and expansion and contraction is not effectively revealed in all-weld-metal tensile specimens. This indicates that the process of thermal adjustment does not use up the inherent ductility of the weld metal itself. Residual stresses can cause localized plastic flow at below-yield-point stresses; but after the initial adjustment, the material behaves normally. Bend ductility also appears to be independent of residual stresses. Postweld treatment at 1200° F will almost completely eliminate gross residual stresses in weld metal.

Weld metal behaves like wrought steel in subambient tensile tests. Fisheye defects are not observed in low-temperature fractures because of the transition from ductile to brittle behavior of the weld metal.

At high temperatures, weld metal exhibits a loss in ductility. A ductility

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trough is evident from 900 to 1100° C, and is characteristic of cast steel. A ductility drop at around 400° F is also evident because of strain-aging effects; this is manifested by an increase in ultimate strength, as well as a decrease in elongation and reduction in area.

Rapid cooling of weld metal results in a loss of ductility; this effect does not alter the yield strength or ultimate strength, but is obvious in measurements of ductility. The cooling rate also affects the quantity of nitrides that separates out; much less separated nitride appears in rapidly cooled welds, thus suggesting a coherency mechanism to account for the observed embrittlement. It appears that weld metal deposited with cellulosic electrodes cannot be cooled rapidly from 700° F to room temperature without showing signs of embrittlement. It has been suggested that cooling rates at temperatures as low as 212° F may be important. Preheating will lessen the extent of cooling rate embrittlement and, generally, improves ductility, but excessive preheat temperatures can decrease weld metal strength and promote gas-forming reactions. The low-hydrogen deposits are not as susceptible to embrittlement upon rapid cooling. In some instances, interlayer temperature control, rather than interpass temperature control, seems beneficial for optimum ductility.

The effects of postheating are varied. The common subcritical stress-relief treatment removes high orders of residual stresses, but postheating at temperatures up to 1200° F seems to have little effect on the tensile properties of weld metal. With the higher alloys, stress relieving induces embrittlement. Treatment at 1200° F is effective in removing hydrogen and decreasing fisheyes, and in high hydrogen deposits, ductility is increased by postheat. It has been reported that postweld aging at 200° F improved the tensile ductility of various types of deposits. Low-temperature aging will also accelerate precipitation reactions activated by quenching or straining.

Heating weld metal above the transformation range results in a marked decrease in strength; this loss in strength does not occur at stress-relieving temperatures. The homogenizing effect of normalizing or annealing is beneficial. High-temperature annealing also markedly decreases the weld metal yield-tensile ratio.

Although inconsistencies in welding technique and structural defects can obscure tensile results, the all-weld-metal tensile test appears to be an instructive criterion for evaluating weld metal, and for giving the most quantitative information.

Introduction

Although its carbon and alloy contents are usually lower, mild-steel weld metal can readily be deposited that is as strong as, or stronger than, the base metal it joins. The weld-metal yield ratio, or ratio of yield strength to tensile strength, is generally much higher than that found in either wrought steel or cast steel of a comparable composition. The high yield ratio is usually accompanied by comparatively limited ductility. The factor or factors responsible for these characteristics in weld metal are not obvious, and much of the information appearing in the literature is highly empirical and inconsistent.

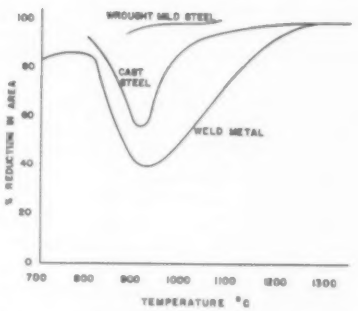

Fig. 1 The ductility of weld metal compared with that of wrought steel and cast steel[7]

The literature review that follows was made prior to undertaking an investigation now in progress to study the factors that affect the strength and ductility of carbon-steel weld metal.

Comparison of Weld Metal to Cast and Wrought Steel of Similar Composition

On the basis of its tensile properties, weld metal compares to cast steel in some respects, and to wrought steel in others. Ball and Winterton[7] cite a similarity between weld metal and cast steel, in that both tended to exhibit a minimum in ductility between 900 and 1100° C. For wrought steel, no such drop in ductility was noted. This is graphically shown in Fig. 1. It was thought that the trough for weld metal was due in some way to the melting process and, by comparison, it was concluded that this was an effect characteristic of a cast steel, as shown in Figs. 1 and 6.

Smith and Rinehart[31] comment that matching the analysis of the base metal does not necessarily provide a match of mechanical properties of the weld to those of either rolled or cast steel, and for specification purposes, chemical analysis alone of the weld metal is not adequate unless the mechanical properties are known. It was stated, however, that weld metal responds to heat treatment similarly to a wrought steel of comparable composition.

For shielded-arc weld metals containing 0.019 and 0.043% nitrogen, Heuschkel[12] demonstrated that the mechanical property trends were similar to wrought steel in the temperature range −300 to 1400° F. In a later investigation,[10] shielded-arc, submerged-arc, and inert-gas-shielded metal-arc weld metals were compared with rolled and annealed iron over the range −300 to 2200° F. More details on this investigation follow in the section dealing with elevated-temperature properties of weld metal.

It is interesting to compare representative mechanical properties of wrought steel, cast steel and weld metal of similar compositions. By referring to Table 1, it can be seen that with similar, or even leaner, alloy contents, the weld metal is much stronger, especially in yield strength. The comparatively high yield ratio of the weld metal generally implies an inferior ductility and work-hardening capacity.

Weld-Metal Structure and Defects

The belief has often been expressed that coarse-grained dendritic weld metal is inferior to refined equiaxed material in several respects. Merrill[35] in investigating the weldability of Mn-V plate steel compared mechanical properties of submerged-arc welds to shielded-arc welds of similar composition. The all-weld-metal tensile tests revealed an ultimate tensile strength of 84,300 psi and elongation of 25.5% for the single-pass, coarse-grained dendritic submerged-arc weld, as compared to 84,000 psi and 22.5%, respectively, for the multipass, refined structure resulting from the covered electrodes.

Structural defects such as porosity can seriously lower weld-metal tensile properties. In inert-gas-shielded metal-arc welding, Christopher and Becker[15] comment that porosity can be caused by an erratic welding arc which creates turbulence in the protective gas shield and increases the likelihood of oxygen and nitrogen entrapment in the weld metal. These authors reported that porosity can be caused by lack of sufficient deoxidizers, such as Si or Al, in

Table 1—Mechanical Properties of Cast Steel, Wrought Steel and Weld Metal of Similar Compositions

Material	*Designation*	*Composition, %*	*Ultimate tensile strength, psi*	*Yield strength, psi*	*Yield strength/ultimate tensile strength*	*Elongation in 2 in., %*	*Reduction in area, %*
Hot-rolled steel[30]	AISI C-1010	0.10 C, 0.45 Mn	51,000	29,000	0.57	38	70
Cast steel[30]	AISI C-1010	0.10 C, 0.60 Mn, 0.40 Si	60,000	35,000	0.58	29	59
Weld metal[35]	AWS E6010	0.08 C, 0.45 Mn, 0.23 Si	67,000	57,000	0.85	26	..

the filler wire. Porosity also depended on the composition of the base plate. It is well known that increased amounts of porosity lead to lower elongation values. This point was well demonstrated by Cook and Rothschild[14] who gave inert-gas-shielded metal-arc deposits A, B, C and D ratings on the basis of the porosity count. It was noted that elongation decreased markedly with inferior soundness rating. On the other hand, Cagnet[52] found that porosity up to seven holes per inch (radiograph count) had no effect on the reduction in area, and decreased the tensile strength but slightly in inert-gas-shielded metal-arc deposits. Of academic interest is Englis' work[53] on stress concentration in steel plates. His stress concentration equation indicates that a spherical shaped void would cause a threefold increase in applied tensile or compressive stress at the periphery of the void in the testing direction. On this basis, one would expect localized plastic flow at the walls of voided gas inclusions, and a net reduction in over-all strength and ductility of the weld metal.

One common structural defect in weld metal is the "fisheye" or "halo" observed in tensile fractures. As with other types of electrodes, Howard[4] found that postweld heat treatment of iron-powder electrode deposits (E6024) reduced the number of fisheyes, and gave rise to a more ductile fracture. By a comparatively long aging time of 24 to 48 hr, it was possible to reduce the number of fisheyes at aging temperatures as low as 200–220° F.

Ludwig's data[3] show that weld-metal soundness, as determined by density, decreased with increasing partial pressure of nitrogen in an otherwise pure argon atmosphere. Above a partial pressure of 0.01 atmosphere (1% nitrogen: 99% argon), the weld metal density decreased rapidly from 7.87 to 6.7 g/cc at a nitrogen percentage of 4.5. Below 1% nitrogen, the weld metal density was consistently close to 7.87 g/cc, the density of 0.06% carbon steel. It has been reported that nitrogen also contributes to fissure formation in weld metal,[34] although hydrogen has been heretofore regarded as the contributor.[20]

Bland[20] associated weld-metal microcracks and low ductility with electrode type and cooling rate of the weld. The number of fissured defects in E6010 weld metal increased as the time interval between welding and quenching to 212° F decreased. It was found that if this interval was less than two minutes, many fissures resulted; no fissures were present if the time interval exceeded three minutes. Low values of elongation were related to the presence of fissures and brittle, woody fractures, but it is noteworthy that the presence of fissures does not necessarily imply low-elongation values. In a low-manganese deposit, Bland noted that a quench time of 20 sec produced fissures, but the fracture appearance was ductile, and the elongation was high. It was explained that fissure formation was related to hydrogen diffusion, and with short quench times, the dissolved hydrogen in the weld metal did not have ample time to effuse. Allowing the weld metal to cool to 700° F before quenching resulted in a fissure-free weld. This is explained if considerable amounts of hydrogen have already effused from the weld during the comparatively slow cooling to 700° F before water quenching to 212° F. Rapidly cooled E6011 cellulosic welds averaged 0.3 cc hydrogen per gram of weld metal as compared to 0.1 cc/g for the E6016 low-hydrogen deposits. Bland concluded that between these extremes of hydrogen lies a critical content, below which no fissures form. The fissures were oriented interdendritically in single-pass welds, and their orientation as well as form were not changed by recrystallization due to the heat effect of additional weld passes. Bland suggested that there was no direct evidence that hydrogen played the main role in fissure formation, and that the peculiar orientation of the defects, transverse to the weld axis, could be associated with quenching stresses or the mechanism of weld metal deposition or solidification.

Oxide inclusions, especially those arising from bare electrodes without a shielding medium, have been responsible for extremely low values in mechanical properties. Gayley and Willis[41] cite bare wire deposits with cavities and oxide inclusions having tensile strengths of 49,000 psi, yield strengths of 35,000 psi, reductions in area of 10% and elongations of 8% in 2 in. In their investigation with covered electrodes, a coarse dendritic deposit was inferior to refined equiaxed weld metal. The optimum refined structure was obtained by depositing thin layers of weld metal by a weaving technique. Welding in this manner promoted rapid freezing, low interdendritic segregation, small dendrite size and resulted in a uniform structure with uniform physical properties. It was reported that excess currents superheated the weld metal and promoted secondary reactions between the weld metal and the coating materials that resulted in gas evolution and porosity.

Hueschkel[10] states that gas voids, slag and inclusions reduce the true fracture stress and ductility, but these effects may not be revealed in measurements of the conventional yield and ultimate strength.

Herres[23] also observed fisheyes and attendant embrittlement in strained weld metal and confirmed the development of these defects at right angles to the direction of the principal stress.

Zapffe and Worden[16] graded weld-metal soundness on the basis of the appearance of a fractographic pattern. It was reported that the toughness pattern of an E6015 deposit with an intentionally high (0.39%) amount of phosphorous was highly inferior. This high-phosphorous weld metal was readily identified by a "floral" appearance of the fracture facets.

Rollason and Roberts[33] showed an interdependence between hydrogen and nitrogen contents, and fissure formation and cracking tendency in weld metal. If the content of one of these elements is low, the tolerance for the other is high without promoting fissuring; however, high hydrogen contents seemed more deleterious than high-nitrogen contents. There was also a correlation between alloying elements and fissure formation; the extent of their findings are given in another section of this paper. It was concluded that C, N_2, H_2 and alloying elements affect fissure formation. In explanation, the authors say that fissuring was due to the embrittling effects of hydrogen on regions of weld metal that were inherently lower in ductility by virtue of the presence of intermediate transformation products of austenite. The volume and properties of such regions were supposedly greatly affected by nitrogen and carbon contents.

Structural weakness explained the marked loss in weld metal tensile ductility between 900 and 1100° C in an investigation by Ball and Winterton.[7] The explanation based on a structural weakness was supported by lower ductility in the transverse direction, i.e., across the plane of weakness produced by major segregation, and by the beneficial effect of annealing (hence homogenization of the structure) on ductility.

Smith and Jerabek[11] reported that submerged-arc welds containing Cr and Mo exhibited consistent weld metal composition from top to bottom and no alloy segregation. However, it is known that Mn and Si contents may vary with the number of passes because of cumulative slag-metal reactions.

Effect of Alloying Elements

As in ordinary low-carbon steels, the response to hardening in weld metal is primarily due to carbon; next in effectiveness are Cr and Mn[31]. In studying low-hydrogen electrode weld metal of different analyses, Smith and Rinehart[31] observed the hardening effect of Si, Ni, V and Mo to be small. It was generally seen that a higher alloy content of the weld metal resulted in a higher as-welded strength.

As is known in wrought steel, Benz

reported Mo to be more effective than Mn in weld metal already containing 1.8% Mn; he observed that the addition of 0.4% Mo (to 1.8% Mn weld metal) caused more martensite than an additional 0.5% Mn. The percent martensite in the last pass of fillet welds was markedly influenced by the manganese content of the weld metal. Because of varying carbon contents in the weld metals, Benz based other conclusions on a carbon equivalent, % C + % Mn/6. The ferrite of the weld metal became more acicular with increasing carbon equivalent, and free ferrite outlining dendritic grains ceased to exist at a carbon equivalent of 0.32. For multipass weld metal, the average hardness increased with increasing carbon equivalent. The tensile strength and yield strength increased with an initial increase and then decrease in the elongation and reduction in area (see Table 2). With weld metal containing 2.0% Mn, the effect of adding 0.4% Mo was to increase the tensile strength slightly and the yield strength markedly without any variation in the tensile ductility measurements, elongation and reduction of area. From the reported data, it can be inferred that the yield-tensile ratio decreased with increasing carbon equivalent (essentially due to an increase in Mn) in C-Mn weld metal. This is not in agreement with data shown by Stout and Doty for as-rolled or normalized plate which indicate that increasing carbon equivalent causes an increase in yield-tensile ratio.[49]

From experience, it has been learned that with submerged-arc welding, deeper penetration and sounder welds are possible with higher percentages of weld-metal silicon content.[26] The silicon content of submerged-arc weld metal usually ranges from 0.20 to 1.00%, and the Mn ranges from 0.45 to 1.60. Excess silicon, above that required for deoxidation, appears in the weld metal. In an investigation to determine the effects of Si in submerged-arc welding, Simon[26] employed bend elongation tests to determine the effect of silicon on weld metal ductility. Within the range investigated, 0.28 to 0.76%, Si had no effect on ductility. Tensile testing revealed that the tensile strength, yield strength and ductility for all submerged-arc welds with varying Si content were equal to or better than those of the mild-steel base plate containing essentially C and Mn. Impact ductility increased with increasing Mn/Si ratios.

In inert-gas-shielded metal-arc welds, Si is the prime deoxidizer; its activity is increased by Mn, and a final product of the deoxidation reactions is manganese silicate. The presence of dark patches of silicate slag on a weld bead is generally indicative that the degree of deoxidation in the weld metal is high, and a sound, porosity-free weld results.[15]

Table 2—Variation of Weld-Metal Mechanical Properties with Carbon Equivalent[48]

Carbon equivalent	0.26	0.32	0.55
Tensile strength, psi	81,000	87,750	114,500
Yield strength, psi	67,000	71,900	86,500
Yield ratio, %	0.83	0.82	0.75
Elongation, %	20.5	29.5	23.0
Reduction in area, %	40.4	71.0	54.3

Christopher and Becker[15] further point out that the alloying action of Si and Mn, in addition to the deoxidation, account in part for the excellent tensile properties in inert-gas-shielded metal-arc weld metal; yield strength, 61,000 psi; ultimate strength, 79,000 psi; and elongation, 30%. The deposits were made in a C1025 semikilled steel.

Rollason and Roberts[33] correlated alloying elements with the number of fissures in the weld metal. There was indication that Mo additions to 0.54% Mn weld metal reduced the number of fissures. Additions were increasingly effective up to 0.8%; however, the trend was negative beyond this point. Small additions, up to 0.35%, of Cr and V were helpful in decreasing the number of fissures, but the number of fissures increased again if either of these elements exceeded 0.35%. Within the composition range investigated, 0.52 to 1.37%, Ni had no effect on the number of fissures. It was observed that low Mn deposits were not defective, but if the Mn content exceeded 0.15%, fissures increased, reaching a maximum number at 0.55%; no additional effect was noted for Mn contents between 0.55 and 1.85%. The effect of alloying elements on the number of fissures is shown in Fig. 2.

The same investigation also revealed some interesting facets with regard to the effects of alloying elements on nitrogen and its distribution in weld metal. Manganese caused an increased amount of precipitated nitrogen in the form of needles. However, in deposits containing Mo, the nitrogen took the form of a nonacicular eutectoid; increasing the amount of nitrogen merely increased the amount of the eutectoid present. The small solubility of isolated nitrides indicated a steeper solubility curve for nitrogen in welds containing 0.80% Mo, as compared to Mo-free weld metal. Chromium caused more isolated nitrides in needle form than in Mo-bearing steels and, compared to Mo, Cr caused a smaller decrease in solubility of nitrides. With Ni, the number of nitride needles was smaller than in the alloy-free welds, and these nitride needles dissolved at relatively low temperatures, compared to the 600° C necessary for solution of needle nitrides in Mn welds. Figure 3 shows the relative effect of alloying elements on the nitrogen solubility.

Nitrogen

Nitrogen is recognized for its embrittling effects on steel when present in very small quantities. Low physical properties obtained with bare electrodes are in part due to the solution of oxygen and nitrogen from the air and perhaps to a subsequent precipitation of compounds of these elements.[37] Sowa, Truckenmiller and Wagner[37] concluded that nitrides, other than needles, increased the hardness of the as-welded structure, without seriously affecting the ductility; these nitrides would disappear upon annealing. If the nitrides were present as needles, a strong embrittling effect was noted.

Heuschkel,[12] in studying low- and high-nitrogen weld metal, noted that low-nitrogen weld metal had a higher strength-elongation product (sometimes taken as a measure of energy absorption), and that high-nitrogen weld metal had a higher tensile strength

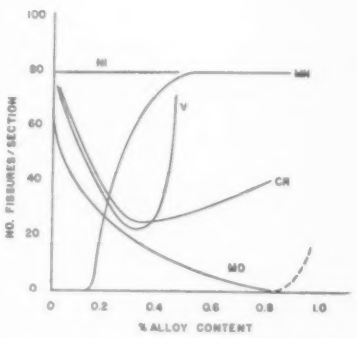

Fig. 2 The effect of weld metal alloy content on the number of fissures[33]

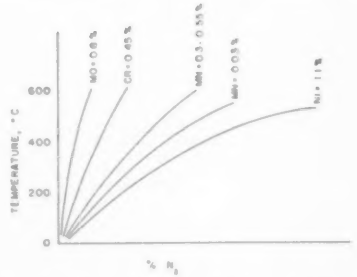

Fig. 3 The effect of alloying elements on the approximate solubility of nitrogen in weld metal[33]

because of iron nitrides. Weld metal containing 0.043% nitrogen did not show fisheyes after postheating at temperatures of 600° F or higher. Fisheyes were present after postheats below 600° F, which somewhat paralleled the findings for hydrogen, and it was stated that similar characteristics result from the presence of nitrogen. The average number of fisheyes per fracture could be related to the weld metal nitrogen content. The high incidence of fisheyes in low-hydrogen welds made with a long arc length established the responsibility of nitrogen.

For weld metal tested in tension at 300° F, the load strain curves indicated strain-aging serrations, even when the nitrogen content was as low as 0.003%,[10] thus suggesting that the irregularity was not due to nitrogen alone.

Heuschkel[10] was able to relate the weld metal nitrogen and oxygen contents to tensile properties. Higher nitrogen contents were more deleterious than higher oxygen contents on the basis that weld metal containing 0.003% nitrogen and 0.005% oxygen had about the same tensile characteristics as weld metal containing 0.003% nitrogen and 0.12% oxygen. At any testing temperature, the lowest ratios of true fracture stress to yield stress were obtained with welds of the highest oxygen and nitrogen contents, and with welds containing mechanical or gas voids. By plotting the difference between the true fracture stress and yield stress vs. test temperature, a ductile brittle transition was obtained; this tensile transition was 350°F below the Charpy V transition for welds of low-nitrogen content. Increased nitrogen content raised the transition temperature for both tests, and decreased the differential between the two. Although somewhat lower nitrogen would be beneficial to impact strength, the upper limit permissible on the basis of tensile properties was fixed at 0.02%.

Rollason and Roberts[32] were also able to relate weld metal nitrogen content to fissure formation. As shown in Fig. 4, it appears that both nitrogen and hydrogen affect the tendency for fissure formation. It was remarked, however, that high hydrogen was more deleterious than high nitrogen. The same authors later presented more data to indicate the importance of nitrogen in fissure formation.[34]

Contrary to Fast, who thought that because of the low diffusion rate of nitrogen in liquid iron, weld metal should retain nearly all the nitrogen appearing in the liquid, Ludwig[7] found that nitrogen was absorbed by weld metal, and then desorbed. This absorption-desorption reaction was thought to account for some porosity. The amount of fixed nitrogen retained in the weld deposits was altered only slightly by the arc heat energy input and its distribution. Nitrogen initially present in the electrode material could be reduced by restricting the nitrogen to a partial pressure of less than 0.005 atmosphere in argon (99.5% argon:0.5% nitrogen).

Oxygen

Inferior mechanical properties have been related to the presence of oxygen in weld metal. This is especially true in bare electrode welding where inadequate shielding causes the number of oxide inclusions to be unusually high.[41] Sowa, Truckenmiller, and Wagner[37] ascribed the low physical properties obtained with bare electrodes to the solution and perhaps precipitation of compounds of oxygen and nitrogen. Schaeffler, Campbell and Thielsch[32] have shown the effect of high-weld-metal oxygen and nitrogen contents on the mechanical properties. The embrittling effect of these elements can be seen from Table 3.

Claussen[28] cites typical oxygen analyses to be 0.035 to 0.26% for ordinary coated electrodes, and 0.009 to 0.017% for lime-base electrodes.

Heuschkel[10] pointed out that the weld-metal oxygen content and nitrogen contents are related, and that higher nitrogen contents are more critical than higher oxygen contents.

In the elevated temperature investigation of Ball and Winterton,[7] oxygen, present as iron oxide, had no effect on the reported loss in weld-metal ductility between 900 and 1100° C.

Hydrogen

The undesirability of hydrogen in steel has long been recognized. Herres[23] pointed out that fully hardened steels which had been subjected to cathodic hydrogen charging were completely embrittled; but the effect was not peculiar to cathodic charging, and could be obtained by annealing for 1 hr in a hydrogen atmosphere at 1600° F. The embrittlement was not a surface

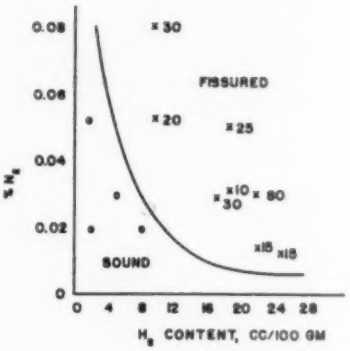

Fig. 4 The relation between hydrogen and nitrogen contents of weld metal and the number of fissures. Figures indicate number of fissures[33]

effect, as evidenced by machining off layers. According to Herres, the tensile strength and yield strength of steels were not significantly affected by hydrogen unless complete embrittlement prevailed. Hydrogen embrittlement was more evident in the reduction of area than in the elongation. This embrittlement became more pronounced with decreasing temperature. Herres proposed that the embrittlement was caused by a precipitation during straining, and became limited by the rate of diffusion of hydrogen.

Flanigan[46] studied weld metal deposited by cellulose electrodes, low-hydrogen electrodes and the submerged-arc process, and was able to ascertain that hydrogen introduced by pickling was more effective in small amounts than hydrogen introduced by welding. Apparently, the total hydrogen content was of less importance than was some effective part of the total. Preheated welds had higher ductility (based on bend ductility) than non-preheated welds, despite their higher hydrogen content. Hydrogen content increased with increasing preheat temperature, and the removal of hydrogen from preheated welds by postheating did not provide an improvement in ductility.

The low bend ductility of rapidly cooled E6010 welds was ascribed in part to hydrogen embrittlement by Flanigan, Bocarsky, and McGuire.[44] As with a previous investigation,[46] it was not the total hydrogen content which was decisive in embrittling. It was conjectured that the embrittlement could also be caused by retention of austenite or precipitation of nitrides.

Schaeffler, Campbell and Thielsch[32] say that the effects of hydrogen on the mechanical properties of weld metal may be assigned to one or a combination of several factors: voids initially present, internal states of stress and strain rate. It can be realized that union of nascent

Table 3—Relationship Between Oxygen and Nitrogen Content and Weld-Metal Mechanical Properties[32]

Material	O_2, %	N_2, %	*Yield strength, psi*	*Tensile strength, psi*	*Elongation in 2 in., %*
Bare wire	0.227	0.150	25–40,000	25–45,000	2.0
Cellulose electrode	0.0448	0.0067	45,000	57,000	35.0

Table 4—Mechanical Properties and Chemical Analysis of Low-Hydrogen and Cellulosic Welds[38]

Electrode	Yield strength, psi	Tensile strength, psi	Yield, ratio, %	Elongation in 2 in., %	% C	Mn	P	S	Si
E6010	55,900	65,600	0.85	23	0.11	0.63	0.012	0.030	0.27
E6016	65,400	75,600	0.86	31	0.11	0.96	0.014	0.022	0.36

hydrogen into the molecular state within voids causes severe internal pressure. Supposedly, this pressure reduces the ductility and toughness of areas surrounding the voids. High internal stresses can magnify the detrimental effects produced by the formation of molecular hydrogen in voids. Straining can intensify this embrittlement by promoting the formation of molecular hydrogen which segregates into regions of dislocations or voided areas. However, on the basis of interaction between solute atoms and dislocations,[57] it is not necessary to postulate the recombination of atoms into the molecular form for an embrittlement mechanism. Hydrogen embrittlement is not evident at high strain rates,[31] assumedly because there is lack of time for diffusion and combination into molecular hydrogen. Slow tensile tests will reveal embrittlement but the effects are less as the strain rates approach impact velocities. It was reported that decreasing strain rates increase the number of fisheyes.[31]

Schaeffler, Campbell and Thielsch say also that fisheyes are characteristics of local embrittlement in the weld. Microexamination at ×1000 revealed distorted metal at the periphery of gas voids in unbent weld deposits.

Simon[17] ranks various deposits in order of decreasing hydrogen content in the weld metal as: E6010, E6012, E6020, E6015, bare electrode (in air), and inert-gas-shielded metal-arc E6010, E6015 and inert-gas-shielded metal-arc deposits are ranked in the same order on the basis of hydrogen evolution in glycerine.[18] A comparison between weld-metal hydrogen content and the shielding atmosphere is shown in Table 5. Increasing strength of weld metal (as caused by alloying) requires a lower moisture content or hydrogen potential in the electrode coating.

Effects of Sulfur

An increase in sulfur content caused weld-metal ductility, impact resistance, and strength to decrease, according to Reeve,[29] This effect was appreciable at 0.07% S, but it was pointed out that this percentage is not likely to be obtained in practice.

This element has long been recognized as a major cause of hot cracking and tearing in steels because of its tendency to form low-melting-point eutectics. These low-melting constituents segregate at grain boundaries and reduce cohesion at elevated temperatures. In one case, Spraragen and Claussen[22] reported hot cracking in weld metal containing 0.035% S, and cite another example where 0.05% sulfur in the base metal had no effect on welding. They claimed that $CaSO_4$ in electrode coatings gave rise to a higher content of sulfur in the weld metal.

As with P, the arc transfer efficiency of S is high in bare-rod welding unless the conditions are unusually oxidizing. With bare electrode welding, the average loss of sulfur was less than 0.005% from electrodes containing 0.04% S in one instance.[22]

High sulfur in weld metal can give rise to porosity in the presence of hydrogen in the arc atmosphere. The hydrogen sulfide voids thus formed have been reported by several investigators.[22,54]

As in wrought steel, sulfur in weld metal appears as a sulfide. The distribution in the latter is comparatively uniform due to the high cooling rate and lack of time for segregation.[22] This uniform sulfide distribution is manifested by a lack of darkening in a sulfur print. Because of the segregated nature of the sulfur in the base metal, as compared to that in the weld metal, it is not surprising that a base metal containing much less sulfur will darken a print, whereas the weld metal may not. In one particular case, weld metal containing 0.07% S did not darken a sulfur print.[22]

Sulfur pickup by the weld metal is probable in welding high-sulfur, free-machining steels, and in welding steels where the segregation is high. Although the over-all sulfur percentage in a plate may be only 0.04, areas of segregation may contain sulfur as high as 0.15%.[22]

Table 5—Comparison of Electrode Type and Weld-Metal Hydrogen Content[17]

Electrode type	% H_2 by volume in arc atmosphere	Wt.-% hydrogen in weld metal
E6010	41.2	0.0014
E6012	35.6	0.0012
E6020	41.4	0.0009
E6015	8.7	0.0003
Bare wire (air)	..	0.0002
Inert-gas-shielded metal arc	..	0.0001

A most effective remedy for combating S in weld metal is the choice of an electrode coating such as the lime-base that produces a basic slag in which the sulfur is retained as CaS.[28]

Effects of Phosphorus

Spraragen and Claussen report that phosphorus is not detrimental to weld metal in concentrations less than 0.15%.[21] Phosphorus in excess of 0.15% decreases ductility and notch toughness. It is well known that phosphorus, like sulfur, has a pronounced tendency for segregation; hence weld metal can pick up P from the base metal areas high in P, although the nominal composition of P in the base metal may not be very high. This element usually occurs in solid solution in steel. It was also reported that no cracking tendency existed when P contents were as high as 0.098%.[21] In bare-electrode welding, phosphorous transfer is high, unless severe conditions of oxidation are prevalent[21] and since most covered electrodes are deoxidizing, efficient P transfer occurs. Fortunately, commercial analyses of base plates and most core wires lie well below the danger zone for P as given by Spraragen and Claussen.

Reeve[29] reports that P has little, if any, effect on ductility in percentages up to 0.128, but he cautioned that the impact value drops when P exceeds 0.07%.

The embrittling nature of high amounts of phosphorus in weld metal were also noted by Zapffe and Worden[18] in studies of weld-metal fracture appearance. A low-hydrogen deposit containing an intentionally high phosphorous content (0.39%) was highly inferior on the basis of its toughness pattern.

Effects of Base Metal Composition and Deoxidation Practice

The mechanical properties of sound weld metal are generally independent of the composition of the base plate or deoxidation practice used in its preparation unless the dilution of the weld metal by the base metal is unusually high. It is likely that a more dominant influence would be exerted by the base metal in the case of submerged-arc welding where the degree of alloying between the weld metal and base metal is more pronounced because of the greater volumetric penetration.[36]

Effects of Electrodes on Mechanical Properties

According to Voldrich, Martin and Rieppel,[24] the mechanical properties of shielded-arc weld metal depend more on the electrode coating than on the core wire. In their investigation, the only significant change of strength or ductility came with varying the coating on the electrodes. Several rimmed, killed and capped low-carbon steel core wires were studied, and it was observed that the weld-metal strength was independent of the type of core wire as well as small variations in its composition.

Daniels, Gardner and Rood[43] commented that both E6010 and E6016 low-hydrogen welds had the same yield strength and ultimate strength if the preheat and energy inputs were adjusted to give the same cooling rate at 1000° F. The elongation of the E6016 welds was consistently equal to or greater than that of the E6010 welds. However, the tensile specimens included the heat-affected zone and the base metal, in addition to the weld metal. Harris, Mathieson and Newmark[38] present a comparison between E6010 and E6016 weld metals which is shown in Table 4. The ductility of the E6016 deposit is seen to be superior to that of the E6010, despite the higher tensile strength and yield strength of the former. From bend test results, Flanigan[46] reported that the as-welded ductility of E6010 welds was the same as comparable low-hydrogen welds made by the submerged-arc process and by means of electrodes having lime-base coatings.

Mathias[5] claimed that as far as the weld metal tensile properties are concerned, the E6024 iron-powder electrodes compared favorably with their E6012 counterpart. For a given grade and condition of material, the product of the tensile strength and elongation was constant. The weld metal from these iron-powder electrodes was amenable to improvement in ductility by low-temperature aging, but it was pointed out that E6010, E6012 and E6020 deposits also behaved the same way.

With inert-gas-shielded metal-arc welds, Cook and Rothschild[14] stated that rimmed electrode wire gave considerable amounts of porosity, and that the killed electrode was superior in this respect. They reported no particular advantage of using deoxidizers such as Al, Zr and Ti instead of Si in electrode metal.

Some of the more highly alloyed deposits have shown a tendency to become embrittled when stress relieved, as shown by Wepfer.[8] This investigator reported an electrode capable of depositing weld metal analyzing 3.5 Ni and 0.50% Mo that is not sensitive to stress relieving embrittlement. This electrode can be classified as E10015.

Flanigan, Bocarsky and McGuire[44] reported that the lime-base low-hydrogen electrodes were immune to low-temperature, high-cooling-rate embrittlement. The cellulose-electrodes were not.

Electrodes that could be classified as basic because of their slag characteristics are effective in combating sulfur in weld metal;[28] hence, poor tensile properties as a result of voids induced by sulfur can be improved by using the basic electrode.

As far as strain-aging tendency is concerned, the E6016 low-hydrogen electrode is not superior to the E6010 cellulosic, the E6012 titania or the E6020 iron oxide electrodes.[42]

Welding Techniques and Variables

Gayley and Willis[41] claimed advantages in using a long rapid weaving technique and thinner layers in multipass welds. This practice produced better than usual ductility, and elongation values as high as 41% were obtained. Corresponding to this particular elongation value was a 69% reduction in area, yield strength of 38,000 psi, and ultimate strength of 55,000 psi; the yield-tensile ratio corresponding to this set of mechanical properties was 0.69, considerably lower than that normally obtained for weld metal. From their data, a trend of increasing ductility with increasing interpass temperatures up to 400° F could be seen. The authors recommended that for optimum mechanical properties, the number of traverses per minute (six to seven times the electrode diameter) range from 60 to 100. In a multipass weldment, the underlying layers are heated through the critical range and the structure is refined, interdendritic segregation is decreased and the extreme underlying layers may be stress relieved. It was reported that the rapid-traverse, thin-layer technique increased all of these heat-treating effects. Higher deposition rates were also recommended with the caution that superheated metal, due to increased currents, promotes secondary gas-forming reactions.

In contrast, using E6024 iron-powder electrodes, Mathias[5] noticed no significant effect of welding technique on mechanical properties of the weld metal when comparing the full weave, no weave and split-layer methods of deposition. The yield strength and ultimate strength were not affected by the width of the weave. Bland[20] reported that there was no improvement in fracture appearance or physical properties of the weld metal as a result of using a full-weave pass technique.

In determining the effect of welding technique on the transition temperature, Grossman and Shepler[47] observed that welding speed had no effect on ductility, as determined by impact, for E6010, E6020 and submerged-arc welds. Excessive travel speed, however, according to Hruska[38] causes a shallow valley in the top center of the weld contour which could detract from a favorable stress distribution in a weldment.

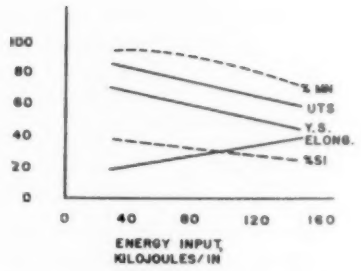

Fig. 5 Effect of energy input on strength, ductility and weld metal composition for shielded-inert-gas metal-arc deposits[14]

In inert-gas-shielded metal-arc welding, Cook and Rothschild[14] noted that high weld elongation resulted from high energy input in one case. The ductility also increased slightly with longer arc length, while the strength remained constant. The more penetrating short arc caused increased porosity and spatter. With increasing energy input, silicon and manganese transfer from the electrode to the weld metal decreased. Their findings are summarized in Fig. 5.

In shielded-arc welding, a short arc yielded a weld-metal nitrogen content of 0.02 to 0.03, while a relatively long arc increased the percentage to 0.05 to 0.06 in an investigation by Rollason and Roberts.[33] Ludwig[3] found that the amount of fixed nitrogen retained in weld deposits varied only slightly with arc heat energy input and distribution.

In addition to increased melting rates, higher currents can cause a more pronounced annealing effect, as suggested by Ball and Winterton.[7] The same investigators found that the loss in weld-metal ductility at temperatures in excess of 900° C could be somewhat rectified by cladding the faces of joints with weld metal. Presumably, this buttering process improved the ductility by lessening the impurity pickup from the base plate.

It has been shown by Stout and Oyler[56] that high currents are responsible for porosity in inert-gas-shielded metal-arc welding. In their investigation, gross porosity was found as the current exceeded a threshold value of about 375 amp.

Flanigan, *et al.*,[44] reported that the hydrogen content of submerged-arc welds may increase with welding voltage.

Various Welding Processes

A most significant contribution, to indicate that weld-metal tensile properties are independent of the welding process has been made by Heuschkel[10] who tested all-weld-metal tensile specimens from −300 to 2200° F. He observed that, for any one tensile property, relatively minor variations exist at room temperature for similar compositions of weld metal made with covered electrode, inert-gas-shielded metal-arc, and submerged-arc welding. Merrill[35] found nearly identical values of strength and ductility for submerged-arc and shielded-arc welds, despite the fact that the submerged-arc welds were dendritic and extremely large-grained, as compared to the refined structure in the multipass covered-electrode weld metal.

Because of extremely high currents used in submerged-arc welding, deeper penetration, hence greater dilution, of the weld metal, should necessarily influence the mechanical properties of weld metal as compared to manual welding with covered electrodes, where the penetration is significantly lower. Hruska[36] has shown that, for a given value of power input, the submerged-arc weld volume is consistently 28% greater than the volume produced in shielded-arc welding. In either case, the weld volume was proportional to the power input. However, with submerged-arc welding, Wilson, *et al.*,[38] have shown that increased electrode extension beyond the contact tip also increases the deposition rate and weld volume.

Residual and Shrinkage Stresses

There is little reason to expect residual stresses to exert any marked effect on either the strength or ductility of weld metal as determined by all-weld-metal laboratory tensile specimens. However, the belief has been expressed that some of the inherently available ductility of weld metal might have been used up by the straining that takes place during its cooling when it is deposited in a structure wherein the plates being welded offer considerable restraint.

Realizing that the highest value of residual stress in a butt weld would lie parallel to the welding direction, and at the mid-point of the weld length, DeGarmo[45] undertook to determine the degree of plastic flow attendant to the process of solidification and thermal adjustment of the weld metal. Tensile specimens were taken from the extreme ends of a submerged-arc bead, where the longitudinal stress would be nearly zero, and strained a known amount in tension; later the prestrained welds were tested to fracture and a plot of increase in yield strength and ultimate strength with increased pre-

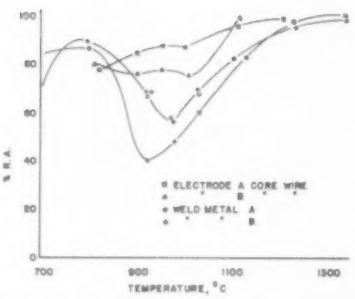

Fig. 6 The effect of temperature on electrode core wire and weld-metal ductility[7]

strain was obtained. By superimposing the normal weld-metal strengths on this curve, it could be seen that the ultimate strength changed almost insignificantly, and that a slight increase in yield strength due to the greatest longitudinal stresses corresponded to a maximum plastic strain of less than one-half percent. It was concluded that this behavior was true for all welds.

According to Boyd,[6] controlled residual stresses produced by local heating in flat bars had a negligible effect on mechanical properties when tested in tension. In regions that were locally heated, plastic flow occurred at loads below the yield point of the virgin material, but after the localized flow, the specimens behaved as if there were no residual stresses. Further static bend tests confirmed the results obtained in tension. It was pointed out that other investigators found that residual stresses were relieved by local plastic flow at less than yield point loads.

Heuschkel[12] commented that stress relieving at 1200° F had little effect on weld-metal properties, but did remove high orders of imposed shrinkage stresses. In bend tests, Flanigan concluded that reductions in gross residual stress by postheating were responsible for little, if any, improvement of ductility.[46]

Weld Metal Properties at Low Temperatures

The literature indicates that relatively little study has been made of the effects of low temperatures on weld-metal tensile properties. Heuschkel[12] studied weld-metal properties from −300 to 1400° F using complete load-strain curves to fracture. From this data shown in Fig. 7, it can be seen that weld-metal elongation at −100° F is actually greater than that at room temperature in welds containing 0.019 and 0.043% nitrogen. Stress relieving at 1200° F in an argon atmosphere had no effect on shifting this ductility maximum from −100° F. The same behavior of weld metal can be seen from Henry's data, as shown by Spraragen and Cordovi;[40] as the temperature decreased from the ambient, the elongation and percent reduction in area increased, and then decreased, although the tensile strength consistently increased with decreasing temperature

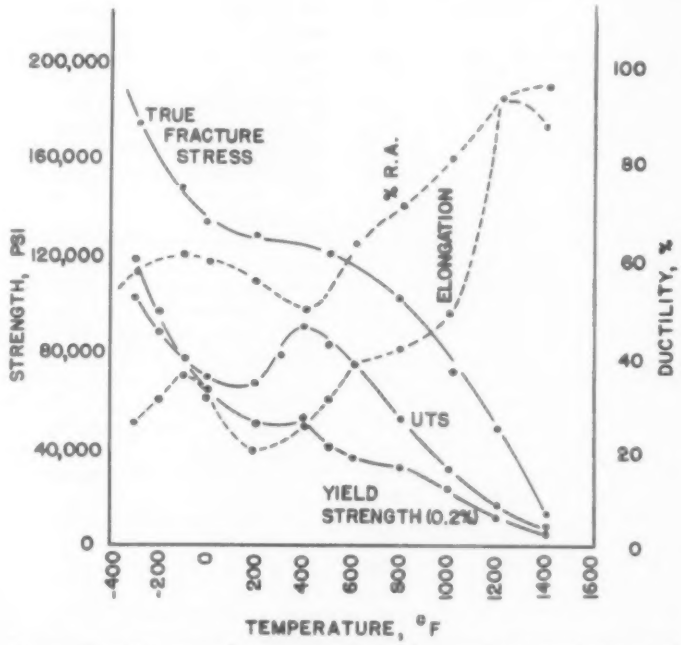

Fig. 7 The influence of temperature on the tensile characteristics of shielded-arc weld metal containing 0.06 C, 0.32 Mn, 0.09 Si and 0.019 N[12]

The ductility maximum occurred at −40° C.

Heuschkel found also that fisheyes were not present in tensile fractures after testing at temperatures below −100° F because the fracture surface was of the granular type. Since the fisheye defect is a gas or slag nucleus surrounded by a rounded area of cleavage within a fibrous type of fracture, its identity is lost when the entire area surrounding the nucleus assumes a brittle like granular fracture. Below −75° F, the upper yield point was greater than the nominal ultimate tensile strength, and in the high-nitrogen weld metal, at −300° F, the upper yield point was equal to the true fracture stress, and completely brittle fracture prevailed. The pronounced difference between the upper yield point and lower yield point of the weld metal gradually decreased as the temperature was raised.

In a later investigation by Heuschkel[10] in which inert-gas-shielded metal-arc welds and submerged-arc welds were compared to covered-electrode deposits, it was generally noted that, for weld metal, the increase in yield strength with decreasing temperature was much more significant than the increase in ultimate strength or true fracture strength. This behavior was the same for all weld metal except for the bare-electrode deposits that failed in a brittle manner at −110° F. The over-all low-temperature behavior pattern of the different weld metals was similar to that of iron. Relatively, the yield strength of iron increased more rapidly per unit of decreasing temperature. This occurs because, for both the weld metal and iron, the stress increase per degree of temperature is about the same, but the yield strength of iron is only one-third that of the low-carbon chill-cast weld metal.

Cooling Rate and Preheat

It is known that rapid cooling of weld metal results in a loss of ductility. In some instances, the tensile and yield strength are not appreciably affected by cooling rate, but the elongation and reduction in area markedly decrease.[32] Rollason and Roberts adjusted the cooling rates of weld metal by varying the plate thickness and by water cooling the bottom of specimens, and concluded that if a weld reached 100° C in less than one minute it would be fissured and low in ductility. For a given plate thickness, fissuring increased with decreasing electrode diameter and hence decreasing current and power input. There was a correlation between the extent of the heat-affected zone and the cooling rate; any heat-affected zone less than 0.11 in. in width was related to fissuring. All deposits studied had reduced ductility when rapidly cooled, but not all of them contained fissures after tensile fracture, thus indicating that fissures were not requisite for reduced ductility. All normally cooled welds showed massive nitrides, but in the rapidly cooled specimens, much less nitride had separated out. This suggests a possible coherency between the ferrite and nitrides, and hence would explain the decreased ductility in the rapidly cooled welds that were not fissured. The addition of Mo appeared to promote the formation of nitrides, even in the rapidly cooled specimens, and it is significant that Mo additions up to 0.8% caused a decrease in the number of fissures. Fissures were observed in *both* longitudinal and transverse directions, and it was stated that the fissures formed below 600° C.

Embrittlement induced by high cooling rates at temperatures below the range of austenite transformation is associated with hydrogen and has been discussed previously.

Flintham[1] concluded that tensile properties of weld metal are impaired by lower interpass temperatures, but stated that this trend can be upset by the unpredictable effect of haloes. It was mentioned that excessively high preheat temperatures, in excess of 250° C, caused low values of yield strength and ultimate strength. Cook and Rothschild also found an increase in ductility and a decrease in yield strength with increasing interpass temperatures.[14]

Gayley and Willis[41] commented on the beneficial value of preheating and stated that the ductility and impact resistance of weld metal increase with increasing interpass temperature. From Doty's all-weld-metal tensile data, it can be seen that a rising interpass temperature decreased the strength and increased the ductility of high-strength shielded-arc deposits when tested in both the as-welded and as-stress-relieved condition.[2]

Christopher and Becker[15] claimed that high interpass temperatures (above 600° F) promoted gas forming reactions and increased porosity in inert-gas-shielded metal-arc welds. It was also suggested that the absence of a protective slag in this welding process could increase the cooling rate. Speculation can also be made regarding an increased cooling rate because of the continual impingent flow of gas on the weld as compared to the cooling rate if the weld metal would solidify in nonturbulent air.

Howard[4] suggested using interlayer temperature control rather than interpass temperature control to improve the as-welded ductility of iron-powder E6024 deposits. Ductility increased and strength decreased with increasing interlayer temperature.

Postweld Heat Treatment

The effects of the customary postweld stress-relief heat treatment at 1150 to 1250° F are varied. This type of heat treatment can increase, decrease or have no effect on the weld-metal strength and ductility. At best, it can be said that the alloy composition of the deposit seems to dictate the response to stress-relief treatments.

Heuschkel[12] stated that stress relieving at 1200° F had little effect on weld-metal properties, but did remove high orders of imposed shrinkage stresses. In his investigation, the tensile properties of weld metal containing 0.019% nitrogen were little influenced by exposing all-weld-metal tensile bars to temperatures between −300 and 1200° F for 1 hr, before testing at room temperature. In high-nitrogen weld metal (0.043%) the pretesting heat treatments above 600° F eliminated fisheyes in the fracture section.

Wepfer[8] noted an embrittling effect from stress-relieving E12015 high-alloy deposits. Stress relieving increased then decreased the strength and progressively decreased the elongation and reduction in area. He reported an electrode that gave a deposit containing 3.5% Ni and 0.5% Cr (which could be classified as E10015) that was not sensitive to stress-relief embrittlement.

It is known that postheat is a remedy for fisheyes. Schaeffler, Campbell and Thielsch[32] stated that a postheat treatment at temperatures as low as 400° F for 24 hr was effective in removing fisheyes. Jackson and Luther[19] reported that ferritic weld metal experienced an increase in ductility when aged from 24 to 72 hr at 100° C, and for 1 hr at 300° C. Nick-bend tests showed increased ductility with time, and it was explained that the recovery was not due to retained austenite since other specimens which were cooled to very low temperatures behaved the same way. It is possible that hydrogen effusion or overaging could have accounted for the ductility restoration.

In some cases, an unpredictable trend accompanies stress relieving. For example, in one investigation of E12015 Ni-Mo-V deposits, stress relieving at 1100° F caused an increased yield strength, a decreased tensile strength a decreased elongation and an increased reduction in area.[2]

Flanigan[46] was able to remove hydrogen by postheating at 350° F; there was no change in weld-metal ductility. But heating at 650° F increased ductility in E6010, E6016 and submerged-arc welds. Herres[23] found that tensile ductility was always improved by postheating the weld metal for appropriate times between 200 and 1200° F, and noted that fisheyes, once eliminated, could be restored by heating

the weld metal to higher temperatures and then rapidly cooling it.

Flintham[1] agreed that postheat from 600 to 650° C would reduce the hydrogen content; it was added that the effect of any significant welding defect would not be altered by heat treatment at this temperature.

Low-temperature postheat, or "aging" at about 200° F, seems beneficial in improving ductility of deposits made by low-hydrogen iron-powder electrodes; the yield strength and tensile strength decrease and the elongation increases, according to Howard.[4] Mathias[8] noted that with E6024 deposits, aging for 48 hr at 212° F caused a 50% increase in elongation; room temperature aging for 15 days effected a 20% increase in elongation. Although the ductility changed considerably on low-temperature aging, there was less than a 5% change in either yield or ultimate strength. It was also noted that aging caused a substantial decrease in the number of fisheyes and tears on the machined surfaces of the specimens. Aging at room temperature or at 212° F also caused an increase in elongation in E6010, E6012, E6016 and E6020 deposits. Stress relieving at 1150° F for 1 hr increased the elongation and reduction in area of the iron-powder electrodes considerably, but had little effect on the yield strength or tensile strength.

If the weld metal has been plastically strained, low-temperature aging at 212° F will accelerate the attainment of an aging peak and subsequent restoration of ductility.[42] A ductility restoration at such a low temperature seems more likely to be linked with quench aging.

The results of several investigations indicate that heating weld metal above the critical range and slow cooling it decreases the strength considerably. The variation of yield strength of 0.10 C, 0.50 Si, 1.40 Mn and 0.4–0.5 Mo deposit after different treatments is shown in Fig. 8.[16] It is seen that the yield strength changes little with stress relieving, but the effects of normalizing are pronounced.

Rollason and Roberts stress relieved rapidly cooled weld metal and air-cooled weld metal.[33] It was seen that the treatment at 650° C improved the ductility, but the values obtained for the rapidly-cooled specimens were not as satisfactory as the values obtained for the normally cooled welds heat treated in the same way. It was thought that the lower ductility in rapidly cooled welds that did not reveal fissures may have been due to segregation of some element such as sulfur which diffuses so slowly below 1100° C that heat treatments in the normal temperature ranges would have little effect. Some specimens were quenched from 1200° C to similate the rapid cooling of the weld, and to determine if heat treatment at this temperature would redistribute some segregated constituent. This treatment was duplicated for both rapidly and normally-cooled specimens. No further recovery was brought about by the higher-temperature heat treatment (up to 1400° C), and it seemed probable that the lack of ductility in these rapidly-cooled multipass specimens was due to fissuring after all. It was found that forging such specimens from 900 to 1200° C to a 40% reduction brought about a considerable, but not complete, recovery in ductility. The shear-type fracture was replaced by a more ductile fracture, with only minute brittle zones. Rapidly-cooled specimens which were heated to 650° C before applying the next pass were entirely free of fissures, and it was concluded that without the interpass heat treatment, there was a gradual build-up of hydrogen to a point which eventually caused fissuring. Once fissures formed, hydrogen was supposedly locked up, and the building-up process would have to recommence.

Table 6—Effect of Heat Treatment on Mechanical Properties of Submerged-Arc Weld Metal[11]

Treatment	Tensile strength, psi	Yield strength, psi	Yield ratio, %	Elongation, %
Stress relieved, 1375° F	85,000	65,000	0.76	25.5
Annealed (no details)	67,400	37,400	0.55	35.0

The effect of heating weld metal into the critical range was shown by Smith and Jerabek.[11] No heat-treating details were given, but the effects of annealing as compared to stress relieving are shown in Table 6 for a submerged-arc deposit containing 5.1% Cr, 0.5% Mo, 1.0% Mn and 0.7% Si. It can be seen that the effect on the yield strength following heating above the transformation range agrees with the data presented by Claussen which is shown in Fig. 8.

Criteria for Testing and Evaluation

The all-weld-metal tensile test is the one test that allows several quantitative measurements of strength and ductility of the weld metal *per se*. However, in the as-welded condition, there are many variables introduced, recognized and unrecognized, that lead to inconsistent tensile results even with uniform electrode quality. For example, if haloes or fisheyes occur, the tensile results will be scattered over a wide range because the effect of haloes cannot be consistent, owing to variation in size and position from test to test.[1]

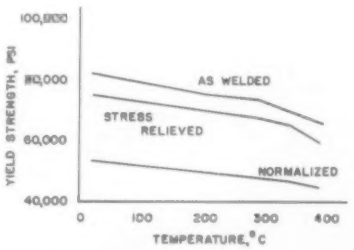

Fig. 8 Variation of weld metal yield strength with temperature and heat treatment[16]

In addition to elongation and reduction in area, an index of ductility is sometimes taken to be the product of tensile strength and elongation[12]; this product is a criterion of the energy absorbed to fracture in tension.

In one investigation,[10] the ratio of the true fracture stress to the yield stress was related to the testing temperature as a means for grading weld-metal quality; this ratio can be extrapolated or projected to a value of unity to obtain the temperature at which brittle fracture will develop in tension tests. In the same investigation the difference between the true fracture stress and yield strength from the tensile test and the Charpy V impact value were simultaneously related to the test temperature to demonstrate that a ductile-brittle transition behavior occurs with either type of test. The tensile transition was 350° F below the Charpy V transition temperature for sound welds of low-nitrogen content. It was claimed that the tensile test and the impact test both lead to the same conclusion if interpreted properly; however, the tensile test is the more revealing of the two.[10]

Heuschkel[10] also offered the suggestion that an index for high levels of performance in weld metal is the potential for strain hardening. High energy absorption was not experienced by the weld metal unless accompanied by an increase in hardness.

Alison[25] stated that the yield strength and tensile strength of mild-steel weld metal are seldom mentioned because it is generally accepted that the weld is stronger than the plate, but the question of ductility of the weld metal, as normally determined by measuring the elongation of an all-weld-metal specimen, is frequently discussed. He claims that the elongation figure so obtained is misleading because there is no relation between the elongation of a machined all-weld-metal specimen and the elongation which will be obtained in a weld in a particular product. He

concluded that the ability of a weld to elongate depends more on the surface condition of the weld than whether the electrode is E6010 or E6012, and that "17% elongation is no criterion, relative or absolute, of the ability of the weld to elongate." Actually, a 17% elongation in a weld becomes meaningless if one considers that brittle service failures have resulted in structures having tensile ductility in excess of 17%. Ball and Winterton[7] claimed that the percent reduction in area is more reliable and consistent than elongation values.

Although the tensile test does have the obvious shortcoming, as do other mechanical tests, of not being able to bridge the gap between laboratory and service, one cannot deny that it gives quantitative information and hence, at least from an academic point of view, is most valuable.

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ATMOSPHERIC WATER VAPOR EFFECTS ON D-C ARC ELECTRODE BURN-OFF RATES

Burn-off rates found to increase with an increase in atmospheric water vapor. An accompanying increase in arc voltage is also observed

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ABSTRACT. Atmospheric water vapor can affect arc characteristics including electrode burn-off rates. Quantitative results are presented here in graphical form, of studies of atmospheric water vapor effects on d-c arc electrode burn-off rates. Arc current was 120 amp. The electrode materials tested were copper, iron and tungsten. The arc ambient atmosphere was air at natural atmospheric pressure with water vapor content controlled and in the range from approximately 0.15 to 16% water vapor by volume.

Burn-off rates were observed to increase with an increase in atmospheric water vapor. An accompanying increase in arc voltage was also observed.

It is suggested that the quantitative information reported may be useful for design for some applications of arcs in natural atmospheres.

Introduction

Arc welding in natural air atmospheres is subject to the natural variations in atmospheric water vapor content. It is known that water in the air or electrode coatings has some effect on the welding process. Accordingly, the specifications for some electrode coatings include a limiting requirement in regard to water content. Also, it has been reported that difficulty has been experienced in holding a welding arc in air in very humid climates using customary equipment. This difficulty is believed to be attributable to excessive water in the air or in the electrodes.

The research from which the results reported here were obtained was undertaken to determine quantitative information on the effects of atmospheric water vapor on welding arc electrode burn-off rates and electrical characteristics.

Reports from previous investigators[1-6] indicated that atmospheric water vapor tends to cause an increase in arc voltage and also causes the emission of strong hydrogen spectrum light from an arc.

It is suggested that information on the magnitudes of the effects of atmospheric water vapor on arc electrode burn-off rates and voltages may be useful in regard to design and use of power supplies, automatic electrode feeds, welding electrodes and so forth where such pertain to arcs operating in natural atmospheres.

The results reported here are from a part of a research program on the fundamental characteristics of high-current arcs which has been in progress during the past several years in the Department of Electrical Engineering at The Johns Hopkins University, Baltimore, Md.

Experimental Procedure

D-c arcs in the current range of 20 to 200 amp were studied operating in air at atmospheric pressure under controlled conditions of atmospheric water vapor content.

The following conditions apply to the results reported here on atmospheric water vapor effects on arc electrode burn-off rates:

1. The concentrations of atmospheric water vapor in air were in the range from approximately 0.15 to 16% water vapor by volume. A concentration of 0.15% water vapor by volume corresponds approximately to the conditions for natural dry weather at approximately plus 15° F. A 6.4% concentration corresponds to 100% relative humidity at 100° F.

2. Arc current was 120 amp dc. This was selected as being satisfactory for illustrating the point.

3. Electrode materials were: (a) $^1/_4$-in. diam copper rods, (b) $^5/_{16}$-in. diam iron rods, and (c) $^1/_4$-in. diam tungsten rods.

4. Electrode separations were in the range of 0.5 to 2.0 cm.

Electrode burn-off rates were determined by use of arc actuated, automatic timing equipment for measuring the length of arc burning time and by use of analytical balances for measuring the weights of electrode burned off.

Results

Figure 1 illustrates graphically the results being reported here on electrode burn-off rates. The ordinate scale shows burn-off rates in units of grams per minute. The abscissa scales show atmospheric water vapor content expressed in several systems of units. The top abscissa scale shows atmospheric water vapor content in units of percent water vapor by volume. For comparison with this, the second scale shows corresponding values of absolute humidity and the third scale shows corresponding values of relative humidity for a temperature of 100° F.

The curves of Fig. 1 for both the positive and negative electrodes for both copper and iron show a definite increase in burn-off rates for an increase in atmospheric water vapor, whereas, the curves for tungsten electrodes show an increase in burn-off rate for the negative electrode but no observed increase in burn-off rate for the positive electrode.

As companion information to that shown in Fig. 1, Fig. 2 illustrates arc voltage as a function of atmospheric water vapor content under conditions similar to those for Fig. 1 except that the electrode separation is one centimeter. The characteristics of these curves are somewhat similar to those of Fig. 1.

Table 1 is derived from the information shown in Figs. 1 and 2. This table sets forth a comparison of percentage increases in electrode burn-off rates and arc voltages, above the burn-off rate and arc voltage values at 1.9% water vapor by volume, for a change in atmospheric water vapor from 1.9% to 6.4% water vapor by volume.

The information reported here shows

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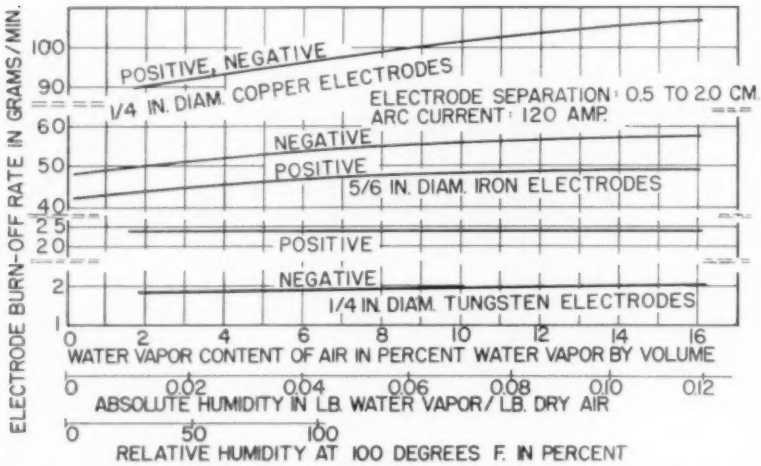

Fig. 1 Effect of atmospheric water vapor on d-c arc electrode burn-off rates

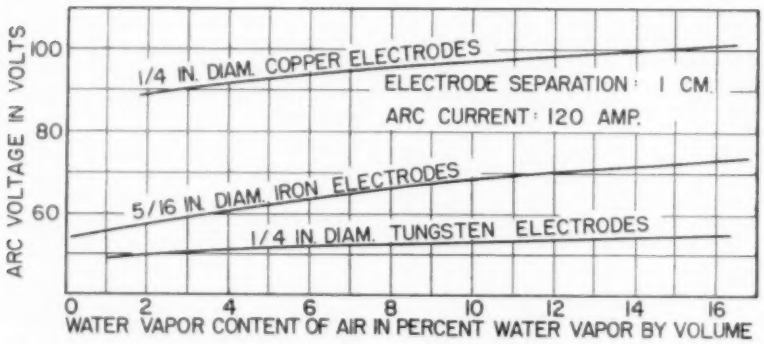
ARC VOLTAGE IN VOLTS
100
80
60
1/4 IN. DIAM. COPPER ELECTRODES
ELECTRODE SEPARATION: 1 CM.
ARC CURRENT: 120 AMP.
5/16 IN. DIAM. IRON ELECTRODES
1/4 IN. DIAM. TUNGSTEN ELECTRODES
0 2 4 6 8 10 12 14 16
WATER VAPOR CONTENT OF AIR IN PERCENT WATER VAPOR BY VOLUME

Fig. 2 Effect of atmospheric water vapor on d-c arc voltages

that an increase in power consumption is attendant to burn-off rate increases arising from an increase in atmospheric water vapor, assuming other factors remain the same. It also shows that this increase in power is obtained through an increase in arc voltage.

The increases in electrode burn-off rates which accompany increases in atmospheric water vapor appear to be at least partially attributable to increased chemical action in the case of the negative tungsten electrode but to be mostly attributable to increased rate of energy transfer to the electrodes in the case of copper and iron electrode materials.

Summary

The results disclosed here have shown quantitative information on the increases in electrode burn-off rates caused by atmospheric water vapor for several electrode materials and for a range of values of atmospheric water vapor content which embraces essentially all values which occur naturally except possibly for those values occurring under extremely dry conditions. The results have also shown the arc voltage increases associated with the burn-off rate increases.

This information may merit consideration in respect to certain design work involving the use of arcs in natural atmospheres.

Table 1—Electrode Burn-Off Rate and Arc Voltage Percentage Increases for Change in Atmospheric Water Vapor from 1.9% to 6.4% by Volume Under Conditions Stipulated in Figs. 1 and 2

Electrode material	*Approximate increases in electrode burn-off rates* — *Positive electrode*	*Negative electrode*	*Approximate increase in arc voltage*
Copper	8%	8%	7%
Iron	8%	8%	12%
Tungsten	(none observed)	6%	4%

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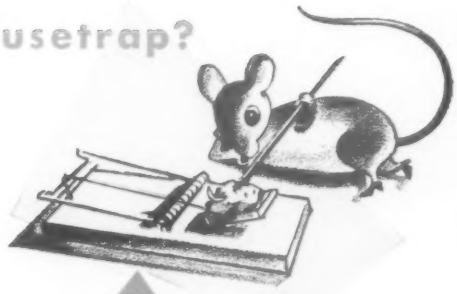
How do you make a better mousetrap?

A recent coast to coast survey of all mice to get an answer to this age-old problem revealed a startling fact. The overwhelming opinion was that there was no need for a better mousetrap. It was found that the death rate of both male and female mice reached an all-time high in 1956. In some areas the situation had gotten so bad that prizes for the development of new style "Trap-Snappers" were being offered by local chapters of the Benevolent and Protective Order of Mice.



What does it take to make a better electrode holder?

Extensive interviews with weldors from coast to coast revealed that the rate of over-tired, worn-out weldors was on the increase. Much of this worn-out feeling was caused by the use of old style, heavyweight electrode holders. There was an overwhelming opinion that something needed to be done. The answer came from the weldors themselves. They wanted a holder that was lightweight, ran cool and was easy to attach to a cable. Now, weldors are finding the answer to their problems in the NEW AL-300 TWECOTONG Electrode Holder.

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Lightweight

is accomplished by using *forged aluminum* in the tongs which weigh only half as much as copper tongs.

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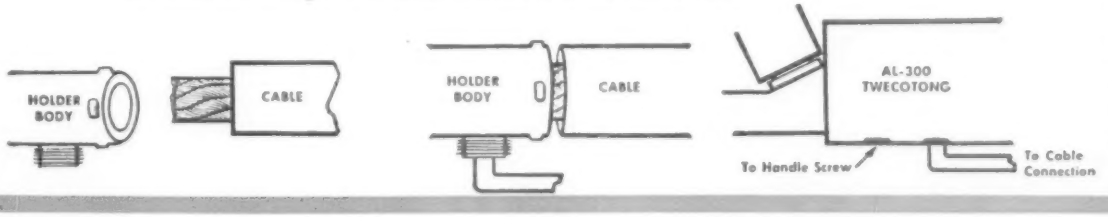
results from the use of proper design and materials . . . pure copper jaws which are cadmium plated; the vise-like grip of the holder jaws on the electrode; and forged aluminum to carry welding current more efficiently than regular copper castings.

And to give Weldors everything they wanted, TWECO developed the ball-point screw method of attaching a holder to a cable. This new connection is the easiest to install, most electrically efficient connection ever put on a holder. Connect it in one minute flat!!



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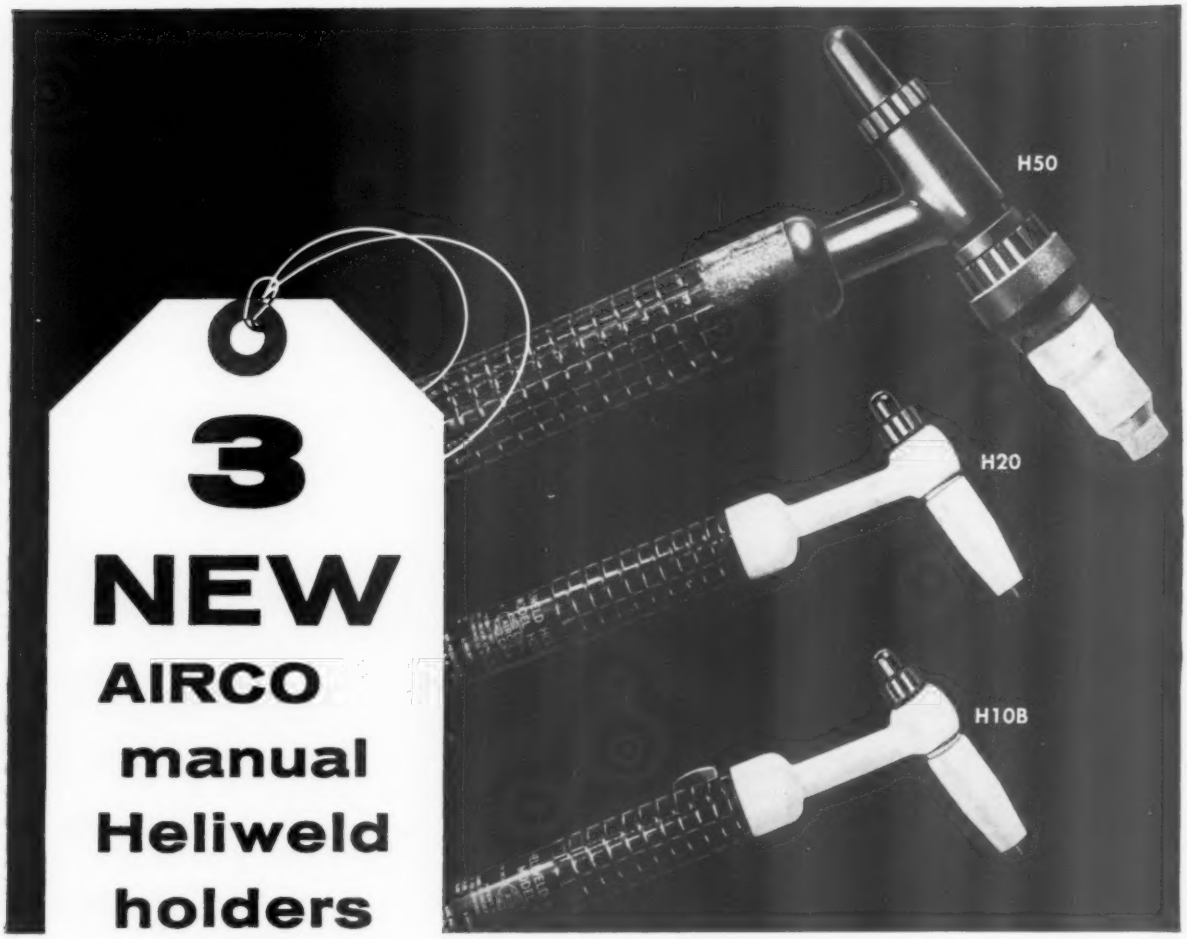

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Wider and higher current ranges of these three new Heliweld holders add a new measure of versatility in the welding of thin gauge sheet aluminum, stainless steel, copper base alloys, magnesium and killed steel.

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